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# MEASURES OF ABSOLUTE WAVE-LENGTHS IN THE SOLAR SPECTRUM AND IN THE SPECTRUM OF IRON.[1]

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## I. INTRODUCTION.

At the present time spectroscopic measures are ordinarily made by referring each line to neighboring lines whose relative wave-lengths have been determined by Rowland. The measures are thus based upon a series of standards, and every accidental error in one of these standards produces systematic errors in the measures of a certain part of the spectrum.

Interference methods permit the ratio of the wave-lengths of any two bright lines to be measured directly. In the form employed by us, they render possible the solution of the same problem either for two solar lines or for a solar line and a bright line. Contrary to the present custom, we therefore select a single standard in the spectrum, and compare all wave-lengths with the wave-length of this standard. This should be a rigorously defined radiation, easily reproduced without change of character.

[1] Communicated by the authors, as advance proof of an article to be published also in the *Annales de Chimie et de Physique.*

The choice of one of the two D lines should certainly be avoided, since these lines are too wide, both in the solar spectrum and in flames, where they undergo remarkable variations in appearance. In the solar spectrum hundreds of lines might serve much better as standards (Peirce). But it is not sufficient that the line selected be narrow : its wave-length must also be constant. The wave-length of solar lines varies very appreciably, depending upon the point of the Sun observed, on account of its axial rotation; the motion of the Earth in an elliptic orbit and its axial rotation may also produce changes which, though very small, may not be entirely negligible in a fundamental standard ; finally, it is not certain that variations in the solar activity may not cause slight changes in wave-length, through change of pressure. Moreover, laboratory methods render possible the production of bright lines whose wave-lengths are much better defined than those of the sharpest solar lines, and which offer every guarantee of invariability.

The problem has been studied and completely solved by Professor Michelson, in connection with another research (choice of a metrological standard). But the conditions of the two problems are precisely the same, and the best metrological standard is also the best standard from the spectroscopic point of view. We shall therefore choose as a standard the red line of cadmium produced by the electric illumination of the vapor at low pressure.

This standard having been chosen, it is desirable to designate its wave-length. From a purely spectroscopic point of view, the choice of this number is only of conventional importance : wave-lengths are used in spectroscopy only as ratios, and the designation of the wave-length of the standard by this or that value is a matter of perfect indifference. It nevertheless seems rational to refer wave-lengths to the unit of the metric system, by attributing to the wave-length of the red cadmium line the value $643.84722\,\mu\mu$ in air at $15^\circ$ and 760 mm, the value found by MM. Michelson and Benoit. If future investigations yield a more exact value of this wave-length, it

will only be necessary to multiply all the other numbers by the same coefficient.

It should be added that, as a matter of fact, the greater part of our determinations have been made by comparison with the green line, which is brighter and more conveniently situated in the spectrum. It is true that this line is not single; but in the conditions of the experiments (Michelson tube excited by an alternating current and not by a coil), the principal component so strongly predominates that this complexity can lead to no error. Furthermore, we have frequently had occasion to determine that the ratio of the wave-lengths of the red and green lines of cadmium given by MM. Michelson and Benoit is accurate to a ten millionth (at least when only the principal component of the green line is considered). Under these conditions it comes to exactly the same thing to take the green line as the standard, giving it the wave-length 508.58240 $\mu\mu$.

To avoid reducing to vacuum, which requires a very precise knowledge of the optical properties of air, the wave-lengths are given in air. These wave-lengths vary with the temperature and pressure; but it is easy to show that the relative wave-lengths remain practically unchanged, at least under ordinary atmospheric conditions.

Thus for a given condition of the atmosphere let $D$ be the density of air, $\lambda$, $\lambda'$ the wave-lengths of the two lines, $n$, $n'$ the corresponding indices of air. If the temperature and pressure vary, we have

$$\frac{\lambda}{\lambda'} : \frac{n}{n'} = \text{const.}, \quad \text{whence} \quad \frac{d\dfrac{\lambda}{\lambda'}}{\dfrac{\lambda}{\lambda'}} = \frac{dn'}{n'} - \frac{dn}{n};$$

but

$$\frac{n-1}{D} = \text{const.}, \quad \text{whence} \quad \frac{dn}{n-1} = \frac{dD}{D},$$

$$dn = (n-1)\frac{dD}{D} \quad \text{and} \quad dn' = (n'-1)\frac{dD}{D},$$

finally

$$\frac{d\dfrac{\lambda}{\lambda'}}{\dfrac{\lambda}{\lambda'}} = \frac{dD}{D}\frac{n'-n}{nn'}.$$

Under the conditions of our measurements, which extend from $\lambda\,435\ \mu\mu$ to $\lambda\,650\ \mu\mu$, the error resulting from a change of pressure of 20 mm of mercury and a temperature change of $15^{\circ}$ (never realized in practice) is less than three ten millionths. As the precision attained is one millionth, no attention need be paid to this point.

The values given may thus be considered to have the following significance: If a line is defined by the value $\lambda$, the ratio $\frac{\lambda}{643.84722}$ is the ratio of the wave-length of the given line to that of the red cadmium line, both being observed in air under the same conditions. Further, if we consider with MM. Michelson and Benoit that the wave-length of the red cadmium line in air at $15^{\circ}$ and 760 mm of mercury is 643.84722, our values represent absolute wave-lengths for the same conditions.

We may remark, in consequence of what has been said, that it is unnecessary to record the temperature and pressure in wave-length comparisons, provided that these quantities do not change during the measures.

*Precision of wave-length determinations.*—Even when we except the compound lines observed by us and previously recognized by Professor Michelson, a spectral line never appears as an infinitely narrow line, such as would correspond to a simple pendular motion, either in the case of a bright line or a dark absorption line. Without the necessity of investigating the physical cause of this phenomenon, it is evident that this appearance must render difficult the determination of the center of gravity of the line, and by this fact in itself prevent the possibility of giving the wave-length with more than a certain number of significant figures; it is just as though we were dealing with a group of lines and not with a single one in the mathematical sense of the word.

It is desirable that the methods of comparison should be sufficiently perfect to permit this limit to be reached; in other words, that they should be free from systematic errors and be affected by only such accidental errors as are involved in the

definition of the quantity measured. Finally, the best defined lines obtainable should be selected as standards.

II. METHOD OF COMPARING WAVE-LENGTHS.

1. *Interpolation methods.*—The purpose of all spectroscopes is to arrange luminous radiations according to a continuous function of their wave-lengths. Of two given radiations, any spectroscope whatsoever will render it possible to determine which has the greater wave-length. If a sufficiently large number of standards of known wave-lengths are available, it will always be possible to find by interpolation the wave-length of any line. This is the method currently employed in both terrestrial and astronomical spectroscopy. It is equally adapted in principle for prism and for grating spectroscopes, though the interpolation is easier in the latter case, as the formula is sensibly linear.

The interpolation method is not a true method of wave-length determination; it assumes that a certain number of lines forming a wave-length scale have already been compared, and the numbers of this scale must be obtained by another method.

2. *Direct comparison methods.*—Every direct measurement of the ratio of two wave-lengths is based on the observation of interference fringes, which are indispensable for the determination of the periodicity of luminous phenomena.

Consider a radiation of wave-length $\lambda$, employed for the production of an interference phenomenon. To any point $A$ in space there corresponds a difference of path $\delta$ and an *order of interference* $p$; we have

$$\delta = p\lambda . \tag{1}$$

For a second radiation of wave-length $\lambda'$, at a point $A'$ (which may coincide with $A$), we have

$$\delta' = p' \lambda' ; \tag{2}$$

whence

$$\frac{\lambda'}{\lambda} = \frac{\delta' p}{\delta p'} . \tag{3}$$

To obtain the desired ratio, it is necessary to measure the ratio of two lengths and two numbers, $p, p'$. This principle may be applied in various ways:

A. GRATINGS.—The orders of interference are in this case very small (never greater than ten); the integral part of these small numbers is known at once.

*Deviation method.*—$p$ and $p'$ are equal *integers*. Then

$$\frac{\lambda'}{\lambda} = \frac{\delta'}{\delta},$$

and this ratio of lengths is derived from angular measures.

*Method of coincidences.* (Rowland and his pupils.)—The points $A$ and $A'$ coincide; $\delta = \delta'$, $p$ and $p'$ are no longer integers, though nearly so; they are small but different (up to 7 in Rowland's measures). The small fractional part of these numbers is determined by direct measurement.

Thus with gratings interference phenomena of low orders are employed, and consequently the numbers $p$ and $p'$ must be determined with great precision. This is possible, thanks to the special properties of gratings, which are based on the fact that there are not merely two interfering waves, but a great number (as many as there are rulings).

B. INTERFERENCE METHODS.—In this case the orders of interference $p$ and $p'$ are, on the contrary, very high, and may attain tens or hundreds of thousands.

Suppose that the points $A$ and $A'$ coincide. As there are no dispersive media, $\delta = \delta'$ (within very small limits) and consequently

$$\frac{\lambda'}{\lambda} = \frac{p}{p'}.$$

$\lambda$ being the standard, known by hypothesis, we have

$$\frac{d\lambda'}{\lambda'} = \frac{dp}{p} - \frac{dp'}{p'}.$$

The relative error of $\lambda$ varies as the relative error of the order of interference. If infinitely narrow lines are employed $dp$ is certainly less than 0.1; the precision may thus be increased indefinitely by increasing the order of interference. In fact, the limit is imposed by the limit of definition of the lines.

It is evident from what precedes that there is no difference in principle between the grating method and interference

methods for the comparison of wave-lengths. The difference consists simply in the very different order of magnitude of the parameters. In the case of gratings, the order of interference does not exceed a few units; it may attain hundreds of thousands in interference methods. Conversely, the order of interference is defined in the case of gratings with very great absolute precision; with ordinary interference apparatus, where there are but two interfering waves, the absolute precision of $p$ can hardly surpass 0.05. The difference between the two methods is still further diminished if it is noticed that in the case of gratings, if $N$ is the number of lines, the difference of path between the extreme waves is $p \times N$. In both cases great precision cannot be obtained without the intervention of waves having great difference of path; only in the case of gratings there are also present a great number of intermediate waves.

From this point of view our interference methods may be regarded as a combination of the two preceding methods; the value of $p$ is as high as in ordinary interference methods and is limited solely by the fineness of the lines; as in the case of gratings, the number of supplementary waves may be great, though always much less than with gratings and not all of the same intensity. It follows from this that the value of $p$ is determined with a precision at least ten times as great as in ordinary interference methods.

Professor Michelson's echelon spectroscope enjoys the same properties, but in it the value of $p$ is determined for each line, while our interferometer enables us to give this the greatest value admissible.

Finally, the properties of our apparatus resemble those of gratings in that it directly separates the various radiations that enter in a confused mixture, which a two-wave system cannot do; we can thus attack problems which seem beyond the reach of the old interference methods (measurement of wave-lengths in the solar spectrum, for example).

The measurement of wave-lengths in absolute value (*i. e.*, by comparison with a unit of length of another kind) has always

been effected by means of interference phenomena. The equation $\delta = p\lambda$ gives $\lambda$ if $\delta$ is known.

The earliest measures of this character must be attributed to Newton, and they have all the precision that could be expected from a spectrum without standards of comparison. Measures which were absolute as well as relative were not taken up again until after the invention of the grating. The method of deviations is the only one available for absolute measures : the wide range of the results obtained is sufficient to indicate the extreme difficulty of the method. Relative measures, as carried out by Rowland by the method of coincidences, attain a precision considered to be one part in a million; it actually is of this order when neighboring lines are compared, but it is notably less when widely separated lines are concerned (see § V). It follows that the grating is an excellent instrument for measurement by interpolation, only fairly good for relative measures of lines widely separated in the spectrum, and bad for absolute measures.

A return was made to interference methods for the purpose of effecting absolute measures. A very interesting first attempt was that of M. Macé de Lépinay in 1886;[1] the grating was employed only as a dispersing instrument. The problem was attacked and solved in a much more direct manner, first by MM. Michelson and Morley and later by MM. Michelson and Benoit. These experiments led to the determination of the absolute wave-lengths of four lines, of which at least two (the red and the green) are perfectly defined. The superiority of interference methods for absolute measures was then demonstrated. Their precision for relative measures is the result of this work. Unfortunately the apparatus was complicated, and the experiments long and delicate. A dozen new lines were compared by M. Hamy with the lines measured by Professor Michelson, by means of much simpler apparatus. Finally, we have used our fringes from silvered plates for the same purpose. Our first measures, made by the method of coincidences, involved a rather extended investigation; since that time we have devised

[1] *Annales de Chim. et de Phys.*, (6), **10**, 166, 1887.

a much simpler method, which is convenient and reliable in practice; this is described in the present paper.

Summing up, we may say that the grating is likely to remain the principal spectroscopic apparatus; although its resolving power can be exceeded by the use of interference methods, particularly by our own, it nevertheless remains without a rival because of its convenience; by interpolation it is capable of

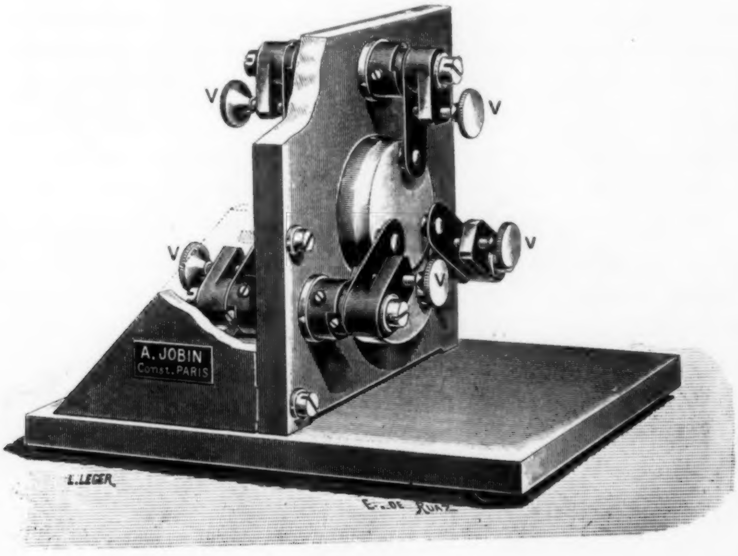



FIG. 1.

giving wave-lengths with a precision attaining a millionth. But this interpolation is possible only with standard lines, and interference methods only can give the relative wave-lengths of these standards to a millionth.

### III. PHENOMENA AND APPARATUS EMPLOYED.

The phenomena which we utilize are always those of interference from silvered films, the theory of which we have given previously. As we are concerned with interference at great difference of path, fringes at infinity are employed, produced by

two plane and parallel surfaces. These fringes consist of concentric circles, whose order decreases as their diameter increases.

The interferometer is employed when we wish to be able to change the order of interference. When this is not necessary, the two plane surfaces are permanently fastened together, parallel to each other, and form what we call a standard of thickness. We have previously described one form of standard;[1] a new and more compact form is shown in Fig. 1; the silvered plates are held against pieces of polished steel, with rounded ends, by springs whose pressure can be regulated by means of the butting screws *V*. By varying this pressure, the deformation of the steel and the glass at the point of contact is very slightly changed, which permits the parallelism of the silvered surfaces to be adjusted, after having been previously made almost perfect by systematically grinding the pieces of steel. The adjustment of these standards is perfectly stable, and their thickness remains almost absolutely constant after successive dismountings and and remountings. We have employed three standards, of 2.5, 5, and 10 mm thickness, respectively.

The method is always as follows: as the two radiations $\lambda$ and $\lambda'$ produce at the same point in the field the orders of interference $p$ and $p'$, we have

$$\frac{\lambda'}{\lambda}=\frac{p}{p'} .$$

The radiation $\lambda$ is always the principal component of the green line of cadmium, produced by the illumination of a Michelson tube through the use of a high tension alternating current, obtained from a small transformer and a converter supplied by a storage battery. Under these conditions the principal component of the green line is predominant, while the others are very faint. Moreover, the tubes last much longer than when excited by a coil; finally, the apparatus is noiseless and the interrupter of the coil, always a source of trouble and uncertainty, is gotten rid of.

[1] *Annales de Chim. et de Phys.*, April 1901; also ASTROPHYSICAL JOURNAL, **9**, 87, 1899.

In brief, everything depends on the determination of the two numbers, $p$ and $p'$. Each is composed of an integral part, $P$, $P'$, and a fractional part $\epsilon$, $\epsilon'$;

$$p = P + \epsilon . \qquad p' = P' + \epsilon'.$$

A. METHOD OF COINCIDENCES.—In our earlier measures, instead of determining directly the fractions $\epsilon$ and $\epsilon'$, we sought a coincidence of the two systems of fringes, the apparatus being illuminated by the two sources simultaneously. This plan required that a large number of fringes should pass through the field, and when once a coincidence had been found, it became necessary to make observations in order to find the orders $p$ and $p'$ (whole numbers). These observations rendered the work very long. By this method we determined the wave-lengths of the mercury lines, the experiments involving a difference of path of 6.3 cm.

Subsequently we simplified the operations, by always working in the neighborhood of some given thickness. For this purpose we set the interferometer for a known thickness, by means of superposition fringes obtained with the aid of an auxiliary standard. In this manner we measured the lines of various metals produced by our vacuum interrupter.[1]

Even with this improvement the method had several serious disadvantages:

1. The necessity of illuminating the apparatus by two sources simultaneously involved important losses of light.

2. The coincidences are easily observed only when the two ring systems are comparable in brightness, and this condition is not always easy to realize.

3. The search for a coincidence always involves uncertainty, and one can never be sure (when the period is short) of finding one that is exact. For these reasons we no longer recommend the method of coincidences. It may be said, however, that for bright and easily isolated lines it is apparently no less precise than the method we are about to describe, which nevertheless has the

[1] *Comptes Rendus*, **130**, 406 and 492, 1900; *Journal de Physique* (3), **9**, 369, 1900.

advantage of being simpler and more uniform in application, while it is also applicable to much fainter lines.

B. METHOD OF DIAMETERS.—The order of interference at the center of a system of rings is determined directly for the two radiations in succession. It is no longer necessary to illuminate by the two sources simultaneously; the distance between the two silvered surfaces, instead of being variable, should, on the contrary, remain fixed during the measurement; the interference is therefore produced by means of a standard of thickness Consider at first the radiation of cadmium, $\lambda$. It gives a system of rings. Let $p$ be the order of one of these rings, *e.g.*, the first from the center; this easily determined whole number is supposed known. The order of interference at the center will be $p=P+\epsilon$ It is necessary to determine this number $\epsilon$, which ordinarily lies between zero and one. The diameter of the ring considered increases with $\epsilon$; the measurement of this diameter should thus permit $\epsilon$ to be measured, as we shall now show.

Let $e$ be the thickness of the layer of air. The order of interference at the center is $p=\frac{2e}{\lambda}$. In a direction making an angle $i$ with the normal, the order of interference is

$$\frac{2e}{\lambda}\cos i = p\cos i \ .$$

If $x$ is the angular diameter of the ring $P$, the observing telescope being focused for infinity, we have

$$p\cos\frac{x}{2} = P \ ,$$

or since $x$ is small,

$$p = P\left(1+\frac{x^2}{8}\right) .$$

.Now

$$\epsilon = p - P, \quad \text{whence} \quad \epsilon = P\frac{x^2}{8} \ . \tag{1}$$

Treating in the same way the radiation to be measured, $\lambda'$, we have

$$\epsilon' = P'\frac{x'^2}{8} \ , \tag{1'}$$

and if the integer $P'$ is known, we may derive from it $\lambda'$ as a function of $\lambda$; thus

$$\lambda(P+\epsilon)=\lambda'(P'+\epsilon')\,,\ \text{whence}\ \lambda'=\lambda\frac{P+\epsilon}{P'+\epsilon'}\,,$$

or, substituting for $\epsilon$ and $\epsilon'$ their values, and making permissible approximations,

$$\lambda'=\lambda\frac{P}{P'}\left(1+\frac{x^2}{8}-\frac{x'^2}{8}\right)\,. \qquad (2)$$

Thus the ratio $\frac{\lambda'}{\lambda}$ is derived from angular diameters $x$ and $x'$ and whole numbers $P$ and $P'$.

*Arrangement, adjustment, and measurement of the standard.*—It is indispensable that the standard be rigorously adjusted, *i. e.*, that the plane silvered surfaces be exactly parallel. A slight maladjustment may produce important systematic errors. If the two radiations do not illuminate exactly the same part of the standard, and if the surfaces are not precisely parallel, the result will be the same as though there were a difference in path when substituting one radiation for the other.

The standard is carried on a support provided with rack and pinion which permits it to be moved horizontally or vertically in its own plane. In front, carried by an independent support, is a screen pierced by a small opening (2 or 3mm in diameter) upon which is projected the image of a monochromatic source. A very small part of the standard is thus used, and the region employed may be changed by moving the standard. If the adjustment is perfect, these displacements will have no effect on the appearance of the rings; if not, the rings will expand or contract. The least defect in adjustment and the precise change necessary to produce perfect parallelism is thus indicated to the observer. The adjustment is effected by varying the pressure of the springs on the steel buttons. The precision of this adjustment is limited only by the curvature of the glass plates, which is always very slight. A position is reached for which the thickness is a maximum or a minimum in the central region; over a limited area it may be regarded as absolutely constant; this area only is used, the standard remaining henceforth fixed with reference to the

perforated screen, upon which are projected the images of the sources employed. The systematic error referred to above is thus certainly avoided, since the part of the standard used is small and perfectly defined, and also since the parallelism of the silvered surfaces is perfect in this region.

The standard, after being adjusted, is measured in terms of the cadmium wave-lengths by the methods already described; it is necessary to use the interferometer for this purpose. The thickness is subject to variation only as the result of expansion; the 1cm standard expands about $0.1\mu$ per degree, or 4 fringes for $10^\circ$. The coincidences of the red and green lines of cadmium enumerate the green fringes by fives. A glance into the telescope indicates the numbers of the various fringes; they remain the same from day to day. Thus $P$ is known at once.

Although temperature changes have no influence on the integral part, they nevertheless produce troublesome variations in the fractional part of the order of interference (for the 1 cm standard, $0^\circ.01$ produces a change of 0.004 fringe, which exceeds the limit of precision). As a complete measure lasts only a few minutes, these variations are easily avoided; they can also be eliminated by making the measures in the proper order.[1]

When sources giving numerous monochromatic radiations are employed, a suitable dispersive system must be used to separate them. Sometimes absorbing tanks are sufficient. In the case of cadmium we observe directly, each radiation gives its own system of rings, and as there are but few of these, settings can easily be made on any ring unless the ring observed corresponds to a coincidence, when an absorbing tank is necessary.

*Measurement of the diameters*—The essential part of the measurement consists in the determination of the angular diameter of

[1] It will be advantageous to avoid these displacements by employing the metal *invar* in the construction of standards. One advantage would be lost, however: with steel standards, the fractional part is quite variable from day to day; if a measure is repeated, it is made again in quite different conditions, which gives a chance control on its exactness. With the metal *invar* great temperature changes would be necessary to appreciably affect the diameter of the rings, and each measure would always be repeated under the same conditions, especially in the case of standards of small thickness.

a ring for each of the radiations to be compared. For this purpose we employ a telescope focused for parallel rays, and provided with an eyepiece micrometer; the objective has a focal length of 19 cm. The magnification should not be too great; we ordinarily use an eyepiece of 3 cm focal length, giving a magnification of only five diameters. The micrometer has a single movable thread; there is also a fixed thread parallel to the movable one. The telescope, carried by a massive cast-iron column, is provided with all motions of adjustment; in particular, it is movable about a horizontal axis by means of a screw.

A measure of the diameter of a ring is made by setting the fixed (horizontal) thread on the upper part of the ring and the movable wire on the lower part, each bisecting the ring. The micrometer has been calibrated with the aid of a large circle divided by Brunner—belonging to the University of Marseilles. The viewing telescope and the telescope attached to the circle having been directed toward each other, with the objectives face to face, the movable micrometer thread was set on the thread of the goniometer for a series of angular positions 5 minutes apart. The resulting measures are well represented by the formula

$$a=(l-3.93)\times 9'.1060\,.$$

$a$ being the angular separation of the two threads, expressed in minutes, and $l$ the position of the movable thread, expressed in revolutions of the screw.

In the measurement of the diameter of a ring made as indicated above let $l$ be the reading of the micrometer in revolutions; the diameter of the ring in revolutions is

$$\delta = l - 3.93\,.$$

In minutes this diameter is

$$a = 9'.1060 \times \delta\,,$$

and in radians

$$x = 0.002649\,\delta\,.$$

The fractional part of the order of interference at the center is

$$\epsilon = P\delta^2 \times 0.87728 \times 10^{-6} = BP\delta^2\,,$$

where

$$B = 0.87728 \times 10^{-6}\,.$$

Similar formulæ will be obtained for the second radiation, $\lambda'$. Thus formula (2), which gives $\lambda'$, becomes

$$\lambda' = \frac{P\lambda}{P'}(1 + B\delta^2 - B\delta'^2) .$$

*Precision of the measures.*—The maximum accidental error of $\epsilon$, for a single measure of the diameter, is less than 0.01, when the radiation which produces the fringes is very nearly monochromatic. An example of the measures follows:

2.5 mm standard: green line of cadmium; number of the ring measured, $P = 9612$. The formula then gives

$$\epsilon = 0.8433 \times 10^{-2}\delta^2 .$$

| Observer | $\delta$ | $\epsilon$ | Mean |
|---|---|---|---|
| Fabry | 11.45 | 1.105 | 1.104 |
| | 11.44 | 1.103 | |
| | 11.45 | 1.105 | 1.106 |
| | 11.46 | 1.107 | |
| Perot | 11.47 | 1.109 | 1.105 |
| | 11.44 | 1.103 | |
| | 11.44 | 1.103 | |
| | 11.48 | 1.110 | 1.110 |
| | 11.47 | 1.109 | |

The horizontal lines indicate a few minutes' rest. The temperature was rising very slowly, which explains the slight increase in $\epsilon$ (about 0.006). It is evident that in a single determination $\epsilon$ may be considered reliable to a few thousandths. $\delta$ is determined in this case to one division on the head, *i. e.*, the angular diameter of the ring is measured within about 6″.

This example suffices to show that the errors possible in the determination of these fractional parts are much smaller than in the case of ordinary interference fringes. This results from the appearance of the fringes: each ring appears as a sharply defined circle, and the thickness of the line hardly exceeds a tenth of the distance between the two fringes. Assuming the fractional part of the order of interference at the center to be

0.9, which indicates that the center is barely luminous, the diameter of the first ring for the 2.5 mm standard and $\lambda$ 500 is $1^\circ 32'$, and its width is only $2'.5$.

Repetition of the measures reveals only the accidental errors; but systematic errors may also affect the results. The fractional part of the order of interference at the center may be deduced from the measurement of any one of the rings. It is advantageous to employ the smaller ones, for a given angular error affects the order of interference at the center by an amount which decreases with the diameter of the ring. Nevertheless, settings on the very small rings involve an error due to the fact that the geometrical middle of the ring and the light maximum which defines the physical middle do not coincide. This arises from the fact that the law of distribution of the fringes is not linear, but is given by a cosine, and may be considered parabolic.

Let $N$ be the order of a ring, $y$ the angular distance from the physical middle point of this ring to the center, $N+\epsilon$ the order of interference at the center; then

$$N=(N+\epsilon)\cos y\ , \quad \text{or} \quad \epsilon=N\frac{y^2}{2}\ .$$

If the edges of the ring are defined by the radii $y'$ and $y''$, and if its semidiameter expressed in fringes is $a$, we have

$$\epsilon-a=N\frac{y'^2}{2}\ , \quad \epsilon+a=N\frac{y''^2}{2}\ ,$$

whence

$$y'^2+y''^2=2y^2\ .$$

In practice we measure the radius $y_1$, defined by

$$y'+y''=2y_1\ ,$$

whence we obtain

$$\epsilon_1=\frac{Ny_1^2}{2}\ .$$

The error involved is

$$\epsilon-\epsilon_1=\frac{N}{2}(y^2-y_1^2)=\frac{N}{8}[2(y'^2+y''^2)-(y'+y'')^2]\ ,$$

whence

$$\epsilon-\epsilon_1=\frac{N}{8}(y''-y')^2,$$

which may be written, after expanding and substituting for $y'$ and $y''$ their values in terms of $\epsilon$ and $a$,

$$\epsilon - \epsilon_1 = \frac{\epsilon}{2}\left(1 - \sqrt{1 - \frac{a^2}{\epsilon^2}}\right) = \frac{a^2}{4\epsilon} .$$

The measured order of interference will thus be too small, and in greater degree as $\epsilon$ grows smaller; in fact, special measures have shown that the values of $\epsilon$ derived from settings on the first ring when barely visible and on the second ring have slightly different fractional values, as the following table indicates :

| | I | II | III |
|---|---|---|---|
| First ring, $\epsilon_1$ | 0.237 | 0.121 | 0.087 |
| Second ring, $\epsilon$ | 1.244 | 1.130 | 1.093 |
| $\epsilon_1 - \epsilon$ | 0.007 | 0.009 | 0.006 |

These differences are clearly in the direction expected, and give for $a$:

| | | | |
|---|---|---|---|
| $a$ - - - - - - | 0.060 | 0.057 | 0.054 |
| Mean - - - - - - | | 0.057 | |

If it is desired that the error be less than 0.005, we must have for the silvered surfaces in question

$$\epsilon > \frac{(0.057)^2}{4 \times 0.005} \quad \text{or} \quad \epsilon > 0.4 .$$

We may add that the direct measurement of the width, made by determining the order of interference at the center for a barely visible ring, in the third of the above experiments, gave $a = 0.052$, which is in perfect agreement with the computed value, in spite of the extreme difficulty of the measures, in which the order of interference is determined to about $\frac{1}{2000}$. We have treated this matter in some detail, as the above results indicate the extreme precision of our measures.

It follows from this that results which are somewhat in error may be obtained if the settings are made on too small a ring; if the first ring is of too small diameter ($\epsilon < 0.3$, for example), the next one would be measured. $\epsilon$ will then be between 1 and 2;

the formulæ are not changed, $P$ always remaining the number of the ring measured.

Thus we see that $\epsilon$ and $\epsilon'$ are known with an absolute error which is certainly less than 0.01; the same is true of the orders of interference $p$ and $p'$, which are obtained by adding whole numbers to $\epsilon$ and $\epsilon'$. Let us now find the precision of the result $\lambda'$.

The equation $\frac{d\lambda'}{\lambda'} = \frac{dp}{p} - \frac{dp'}{p'}$ shows that as $dp$ and $dp'$ are less than 0.01, in order that $\lambda'$ may be known to $\frac{1}{1,000,000}$, it will suffice that $p$ and $p'$ be of the order of 10,000, *i. e.*, that the thickness of the standard shall be from 2 to 3 mm.

For a broad line the rings will of course be less sharply defined, the settings less precise, and the result less exact, but this is due to a lack of definiteness in the aspect of the object measured. After a certain limit has been reached nothing is gained by using rings of a higher order; the rings may even become so ill-defined that measurement is wholly impossible.

Finally, in order to compute $\lambda'$, it is necessary to know the whole numbers $P$ and $P'$, the orders of the rings whose diameter is measured. We have seen that the first, which corresponds to cadmium, is always known without difficulty. $P'$ is deduced from an approximate value of $\lambda'$. In the equation

$$\lambda' = \frac{P\lambda}{P'}(1 + B\delta^2 - B\delta'^2)$$

the parenthesis is known, and also $\lambda$ and $P$. If we give to $\lambda'$ an approximate value, an approximate value of $P'$ may be obtained. If the value of $\lambda'$ is in error by the amount $d\lambda'$, the value of $P'$ will be in error by the amount $dP'$, and we shall have

$$\frac{dP'}{P'} = -\frac{d\lambda'}{\lambda'}.$$

This error, $dP'$, must be so small as to introduce no ambiguity in the whole number to be chosen for $P'$. In general, this condition will be satisfied if the error $dP'$ has an absolute value less than $\frac{1}{3}$. In this case

$$\frac{d\lambda'}{\lambda'} < \frac{1}{3P'}.$$

For instance, if a standard of 2.5 mm is used, $P'$ is of the order of 10,000, and it will suffice in general that $\lambda'$ be known to $\frac{1}{30,000}$. For all the radiations that we have measured we already have values of $\lambda'$ whose precision exceeds this limit; it has not been advantageous to employ a standard of less thickness.

*Order in an experiment.*—To eliminate the effect of changes of temperature, it is desirable to make the measurement of one of the ring systems between two measurements of the other system. We proceed as follows: an observer makes two or three settings on the radiation of cadmium, then two or three on the radiation to be measured, then two or three on cadmium. The mean of all the settings on cadmium is used to calculate $\delta$; the mean of the settings on the radiation $\lambda'$ gives $\delta'$. The second observer repeats the same measures; the observations of the two observers are computed separately and give two independent values of $\lambda'$.

*Influence of change of phase by reflection.*—Let $p$ be the order of interference at the center for a radiation of wave-length $\lambda$. The quantity $e = p\frac{\lambda}{2}$ is, by definition, the optical thickness of the layer of air lying between the two silvered surfaces. Hitherto we have assumed this thickness to be independent of $\lambda$. This is not rigorously true, on account of the change of phase by reflection on the silver, which varies slightly with the wave-length. In other words, it is just as if each kind of radiation underwent reflection at a certain plane, which may be called the optical surface of the silvered glass;[1] this surface varies slightly with the wave-length. It is evident that this phenomenon, which, as we shall see, is extremely small, must modify the results a little. To eliminate it, it is only necessary to make two observations with the same silvered surfaces and very unequal differences of path. The same result may be attained by making a preliminary

[1] The actual surface of silver, which would be extremely difficult to define, has no part in these purely optical questions.

study of the phenomenon in order to derive the corrections which it involves for the wave-lengths computed by the formulæ given above.

Let $\lambda$ be the green radiation of cadmium, $\lambda'$ another radiation; for the same layer of air, we shall have the orders of interference $p$, $p'$, and the optical thicknesses $e_\lambda$, $e_{\lambda'}$, differing slightly from each other.

We have

$$2e_\lambda = p\lambda\ , \qquad 2e_{\lambda'} = p'\lambda'\ .$$

whence

$$\lambda' = \frac{e_{\lambda'}}{e_\lambda}\frac{p}{p'}\lambda\ ;$$

instead of which we have calculated

$$\lambda_0' = \frac{p}{p'}\lambda\ .$$

To this value of $\lambda_0'$ it is therefore necessary to add a correction

$$\gamma = \lambda' - \lambda_0' = \frac{p\lambda}{p'}\frac{e_{\lambda'} - e_\lambda}{e_\lambda} = 2\frac{e_{\lambda'} - e_\lambda}{p'}\ . \qquad (1)$$

To calculate this it is only necessary to know the difference of the optical thicknesses corresponding to the two radiations. This difference is evidently independent of the distance between the silvered surfaces. It is determined by special experiments made by means of interferences at small difference of path, of radiations of known wave-length.

The silvered plates are removed from the standard and attached to the interferometer; they are then brought together until they are nearly in contact, so as to produce a thin film with silvered surfaces. The fringes of this film are observed in parallel light, normal to the surface, by means of a telescope set on the thin film.

The apparatus is illuminated simultaneously by two radiations, $\lambda$, $\lambda'$, and, for clearness, let us assume that $\lambda > \lambda'$. In this double system of fringes an exact coincidence between two fringes is sought. Suppose that the $q$th coincidence appears exact, *i. e.*, that a certain fringe of order $p$, due to the radiation $\lambda$, coincides exactly with the fringe $(p + q)$ due to $\lambda'$. Then

let $e_\lambda$, $e_{\lambda'}$, be the optical thicknesses at this fringe of the thin film for the two radiations. We have

$$2e_\lambda = p\lambda \ , \quad 2e_{\lambda'} = (p+q)\lambda' \ ,$$

whence

$$e_{\lambda'} - e_\lambda = \frac{\lambda - \lambda'}{2}\left(q\frac{\lambda'}{\lambda - \lambda'} - p\right) = \frac{\lambda - \lambda'}{2}\rho \ ,$$

in which

$$q\frac{\lambda'}{\lambda - \lambda'} - p = \rho \ .$$

Hence we can calculate $e_{\lambda'} - e_\lambda$, the difference of the optical thickness for the two radiations used in the experiment. (It should be remarked that $\frac{\lambda'}{\lambda - \lambda'}$ is the period of coincidence expressed as a function of $\lambda$.) In this experiment care should be taken not to choose two radiations $\lambda$ and $\lambda'$ which lie too near together.

The search for an exact coincidence really amounts to the measurement of a fringe of one of the systems with reference to the fringes of the other system; but the observation of a coincidence is more simple, and an exact coincidence can be determined with very great precision, as the least inexactness is betrayed by dissymmetry of color. As a matter of fact an exact coincidence is not always found; two are selected which are slightly inexact, the one in one direction, the other in the other; *i. e.*, two which show dissymmetry in the two senses. These will give two values of $\rho$, one of which is too large, while the other is too small. The search for such cases is easily made, as the interferometer permits the fringes to be moved steadily through the field.

This method of coincidences is remarkably precise; it determines the relative position of optical surfaces for two radiations to about 0.1 $\mu\mu$ (one ten-thousandth of a micron). The radiations which have been employed are the red and the green of cadmium (644 $\mu\mu$ and 508 $\mu\mu$), and the green and the violet of the mercury arc in vacuo (546 $\mu\mu$ and 436 $\mu\mu$).

An example will render clear the procedure employed: Silvered surfaces were used with the 10 mm standard. (These

surfaces are the thickest which we have employed and give the greatest effects of change of phase.) Thickness of the silver film: $61\mu\mu$.

*First observation* (Radiations 644 and 508).—The 29th and 33d coincidences are nearly exact, but one is inexact in one direction, the other in the other direction. They give respectively for $\rho$, 0.037 and 0.077. We adopt 0.065, from the appearance of the coincidences, whence

$$e_{644} - e_{508} = - 4.4 \mu\mu \ .$$

*Second observation* (Radiations 644 and 546).—The 24th coincidence is exact. It gives $\rho = 0.042$, whence

$$e_{644} - e_{546} = - 2.1 \mu\mu \ .$$

*Third observation* (Radiations 546 and 436).—The coincidences 40 and 41 are inexact, one in one direction, the other in the other, and give for $\rho$, 0.140 and 0.094; adopting $\rho = 0.12$, we have

$$e_{546} - e_{436} = + 6.6 \mu\mu \ .$$

Reducing all the results to the line 508, we obtain by differences:

| $\lambda$ | $e_\lambda - e_{508}$ |
|---|---|
| 644 | $-4.4\mu\mu$ |
| 546 | $-2.3$ |
| 508 | 0.0 |
| 436 | $+4.3$ |

With these four points we can find the curve which gives $e_\lambda - e_{508}$ as a function of $\lambda$ (Fig. 2, Curve A). The corrections $\gamma$ are obtained from this by equation (1), which may be written in the following form: For the line 508 the order of interference is 39,500; for the line $\lambda'$ it will be

$$p' = \frac{39500}{\lambda'} \times 508 \ ,$$

whence

$$\gamma = 2 \frac{e_{\lambda'} - e_{508}}{39500} \frac{508}{\lambda'} \ .$$

The correction curve is deduced from the curve for $e_\lambda - e_{508}$ by multiplying the ordinates by a quantity proportional to the

abscissae (Fig. 2, Curve B). It will be seen that the correction to the wave-lengths does not exceed $3 \times 10^{-4} \mu\mu$, or about half a millionth.

With standards of less thickness the corrections would be greater; but, on the other hand, the silver films which we have studied are the thickest ones employed and are also those which

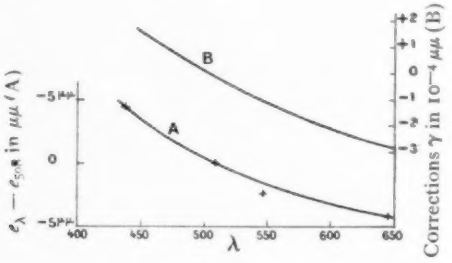



FIG. 2.

have given the largest values for the $e_\lambda - e_{508}$. (The thickness of our silver films varies from 40 to $61 \mu\mu$.)

As a matter of fact the phase correction has never exceeded $8 \times 10^{-4} \mu\mu$, or about one and one-half millionths in relative value. If this correction were out as much as 50 parts in a 100, the millionth would not be affected, and it is known to about 0.1. It is evident that this introduces no appreciable error and that, although the change of phase makes necessary a rather delicate investigation, this phenomenon in no degree diminishes the precision of the result; it is even remarkable that it is necessary to take account of such minute quantities.

[*To be concluded.*]

# THE FLASH SPECTRUM, MAY 18, 1901.[1]

## WAVE-LENGTH DETERMINATIONS AND GENERAL CONCLUSIONS REGARDING THE "REVERSING LAYER."

By S. A. MITCHELL.

UPON the invitation of the former astronomical director of the Naval Observatory, Professor S. J. Brown, the writer became a member of the expedition to view the Sumatra eclipse of May 18, 1901. The party consisted of eleven — six members of the Naval Observatory staff and five invited guests. The former included Professor A. N. Skinner, U. S. N., in charge of the expedition; Professor W. S. Eichelberger, U. S. N.; Professor F. B. Littell, U. S. N.; Mr. G. H. Peters, Mr. W. W. Dinwiddie, and Mr. L. E. Jewell, now of the Johns Hopkins University. The guests of the party were Professor E. E. Barnard, of Yerkes Observatory; Dr. W. J. Humphreys and Mr. H. D. Curtis, of the University of Virginia; Dr. N. E. Gilbert, of Hobart College, and the writer.

A second party, from the Smithsonian Institution, consisting of Professor C. G. Abbot and his assistant, Mr. P. A. Draper, accompanied the Naval Observatory members, the two parties sailing together from San Francisco on February 16. Government steamers carried the expeditions to their destination, the United States army transport "Sheridan" *via* Honolulu to Manila; the United States steamer "General Alava" from Manila to Sumatra, which was reached April 4.

Before arriving in the island it had been decided to occupy two stations for observations on the eclipse; one, Solok, near the central line of totality; the other, Fort de Koch, near the northern edge of the moon's shadow-path.

When we arrived in the East Indies it was soon found that clouds were likely to be exceedingly troublesome, for at no time during the day was the sky perfectly clear. In view of this it was thought best to subdivide the party at Solok, and a

[1] Published in advance of the more complete report by permission of the superintendent of the Naval Observatory.

third station was selected at Sawah Loento, thirty kilometers beyond Solok, at the terminus of the "Staatsspoorweg op Sumatra," the government railroad running inland from Padang. At Sawah Loento were already located Mr. and Mrs. H. F. Newall, of Cambridge, England, and a party from the Massa-

ECLIPSE STATION, SAWAH LOENTO, SUMATRA.

chusetts Institute of Technology under the direction of Professor Burton.

A location was selected near the camp of the latter expedition in the Loento Valley, a mile and a quarter south of the railroad station; and in this connection I wish to express my thanks for the generous assistance of Professor Burton and his party.

The eclipse station was situated 380 meters above sea level, the latitude and longitude being:

$$0^\circ\ 41'\ 52''\ \text{South},$$
$$100^\circ\ 46'\ 40''\ \text{or}\ 6^h\ 43^m\ 6.^s7\ \text{East}.$$

The duration of totality was calculated at 5 minutes 41 seconds.

Two instruments were taken to Sawah Loento, a visual telescope of 15.2 cm aperture, but stopped down to 11.4 cm, and of 264 cm focus, and a spectroscope. The former, used to photograph the corona with orthochromatic plates, was in the hands of Mr. René Granger, of Cartersville, Ga., who rendered me very valuable assistance.

The spectroscope consisted of a Rowland flat grating of of 15,000 lines per inch, having a ruled surface of $3\frac{1}{2} \times 5$ inches, and a quartz lens of 8.53 cm aperture and 183 cm focal length, made by Brashear, the whole apparatus belonging to the Naval Observatory. Light from the Sun, reflected by the coelostat mirror in a horizontal direction, fell on the grating, where it was diffracted and was brought to a focus on the photographic plate by means of the quartz lens. Grating, lens, and plate were enclosed in a box.

The coelostat, driving-clock, and box were mounted on brick piers, in the erection of which some very interesting observations were made on methods of labor in the East—observations not always calculated to increase one's peace of mind when regarding the slowness at which the work progressed.

The grating was employed in the manner which gives a normal spectrum, which is the case when the diffracted ray leaves the grating perpendicularly, or the angle of diffraction is zero. The attempt was made to photograph the first order spectrum from $\lambda$ 3000 to $\lambda$ 6000, hence with $\lambda$ 4500 at the center of the plates.

According to investigations of Mr. Jewell, the focal lengths of the quartz lens for different wave-lengths were:

| $\lambda$ | Focal length | $\lambda$ | Focal length | $\lambda$ | Focal length |
|---|---|---|---|---|---|
| 2500 | 1771.17 mm | 4000 | 1819.00 mm | 5500 | 1833.00 mm |
| 3000 | 1798.98 | 4500 | 1825.78 | 6000 | 1835.84 |
| 3500 | 1809.98 | 5000 | 1829.66 | 6500 | 1837.97 |

It was thus possible to plot the curve on which the spectrum is brought to a focus. On doing this it was found impossible to

procure glass plates which would bend to such a curvature, and it was, therefore, thought advisable to use films. Through the kindness of the M. A. Seed Dry Plate Co. heavy films were coated with their "Gilt Edge" and "Orthochromatic" emulsions. The films used were 38 mm × 305 mm.

The coelostat was one of those built for the 1874 transit of *Venus*, modified this year by the use of a conical pedulum. Even with this improvement, great difficulty was experienced with the coelostat, and it seemed practically impossible to secure perfectly uniform motion of the mirror. The spectrum was focused a few days before the eclipse by Mr. Jewell, by means of a collimator designed by him.

Valuable assistance was rendered on the day of the eclipse by Naval Cadet W. V. Tomb, who counted time, and by Corporal C. W. Keeter, who carefully attended to changing the plates for me, both having come up from the U. S. S. "General Alava" for the purpose.

The day of the eclipse dawned clear, and our hopes were that these favorable conditions would remain till after totality, which occurred shortly after noon. First contact was observed in a perfectly cloudless sky, but soon after this clouds began to gather, and a quarter of an hour before second contact the sky was completely overcast.

The disappearing crescent of the Sun was watched by a binocular, before one-half of which was arranged a small plane grating in such a way that with one eye the spectrum could be seen, with the other the Sun itself. With this, shortly before the time of second contact, bright lines were seen for a few seconds at F and H and in several places in the green and yellow, but these disappeared almost immediately — the Sun being completely hidden by clouds — and the first flash passed without our being able to see it.

Towards the middle of totality conditions became a trifle better, so that it was possible to see, through clouds, the corona extending for about half a diameter from the Sun, and with the small spectroscope the "coronium" line could be seen quite

distinctly. During no time of the 5 minutes and 41 seconds of totality was an unclouded view of the corona obtained, but nevertheless, the second flash was seen beautifully. An hour after the total phase the clouds cleared away and a perfect sky remained for the rest of the day.

Altogether eight plates—or rather films—were exposed, one before and one just after totality for the cusp spectrum, one at first and one at second flash, and four during the total phase with exposures of $12^s$, $120^s$, $90^s$, and $45^s$ respectively.

### DESCRIPTION OF PLATES.

The first plate was taken 10 seconds before the computed time of the second contact, and was exposed for one-half second. It shows the cusp spectrum and about 60 lines between F and H.

As noted above, the clouds thickened at an inopportune time, with the result that nothing appears on the plate exposed for the flash. The four plates exposed during totality show continuous spectrum of a width equal to the diameter of the Sun, and extending from about $\lambda$ 4900 to $\lambda$ 3400, also bright lines of hydrogen from $H\beta$ to $H\eta$ and the helium line $\lambda$ 4471.6, undoubtedly due to the upper chromosphere.

The second flash seemed fully exposed in spite of the clouds.

An exposure was made as soon after totality as possible—probably 5 seconds after third contact—for the cusp spectrum. An exposure of one-half second was given, the plate closely resembling that made before second contact.

### THE SECOND FLASH.

For some reason the spectra were not all of them in perfect focus. As absorption lines suffer from this defect more than bright lines, it was found practically impossible to measure the cusp spectra. For wave-lengths, we are therefore confined to one plate—or rather film,—that of the second flash. This was exposed for three seconds, the exposure being stopped at the first reappearance of the Sun.

The peculiarities of this photograph of the flash are twofold: (1) The normal spectrum, and (2) the great dispersion.

On the plate the distance from F to H is 95.4 mm, and as the spectrum is normal, 1 mm therefore corresponds to a difference of wave-length of 9.37 tenth-meters, or 1 tenth-meter corresponds to a dispersion of about 0.1 mm. This dispersion is about one-fifth of that obtained with the ordinary Rowland mounting with a grating of 20,000 lines and radius of 21½ feet (6.55 meters.)

The plate was measured by one of the Repsold machines belonging to the Columbia University Observatory, by comparing the position of the spectrum lines directly with a millimeter scale. Measures with this machine can be made directly to 0.005 mm, and by estimation to 0.0005 mm, *i. e.*, to 0.005 $\lambda$; the sharpness of the lines, however, did not permit them to be carried to quite this degree of exactness.

Although the spectrum was not in the most perfect focus, in view of the great dispersion measures could be made with a high degree of accuracy. Wave-lengths were determined by taking well-defined standards properly distributed, whose wave-lengths were taken from Rowland's table of standard wave-lengths. Three independent measures of the plate were made.

Second and third contacts were not 180° apart, and the instrument was set up to make a compromise between the two positions. This is the reason for the inclination of the lines of the flash.

### COMPARISONS WITH THE SOLAR SPECTRUM.

Those who have attempted to identify the bright lines with Rowland's map know the difficulty of this undertaking. Great care was exercised in the determinations of the wave-lengths, and in the comparisons with Rowland's tables. For the flash an arbitrary scale of intensities was taken, where 0 means a line seen with certainty, 10 the strongest line, 00 denotes a line seen with difficulty.

Table I contains the results of the comparisons. The spectrum extends from $\lambda$ 4924 to $\lambda$ 3320, but the focus becomes poor at the violet end beyond K, and measures were discontinued at $\lambda$ 3835, $H\eta$.

TABLE I.

| Flash Intensity | Wave-length | Rowland | Substance | Solar Intensity |
|---|---|---|---|---|
| *Hη* 8 | 3835.2 | | *Hη* | .. |
| 2 *d* | 3839.9 | 3838.435 | *Mg–C* | 25 |
| | | 3840.580 | *Fe–C* | 8 |
| 2 | 3859.9 | 3860.055 | *Fe–C* | 20 |
| 2 *d* | 3878.4 | 3878.152 | *Fe–C* | 8 |
| | | 3878.720 | *Fe* | 7 *Nd?* |
| *Hζ* 8 | 3889.0 | | *Hζ* | .. |
| | | 3894.165 | *Cr* | 3 |
| 0 | 3894.2 | (3894.211) | .... | 8 *d* |
| | | 3894.241 | *Co* | 5 |
| 0 | 3895.8 | 3895.803 | *Fe* | 7 |
| 2 *d?* | 3900.5 | 3900.681 | *Ti–Fe–Zr* | 5 |
| 0 | 3902.3 | 3902.399 | *V* | 3 |
| 0 | 3904.2 | 3903.991 | —— | 2 |
| | | (3904.023) | .... | 8 *d* |
| | | 3904.050 | *Fe* | 5 |
| 0 | 3905.7 | 3905.660 | *Si* | 12 |
| 00 | 3907.6 | 3907.615 | *Fe–Sc* | 3 *d?* |
| 2 *d?* | 3913.3 | 3913.609 | *Ti–Fe* | 5 *d?* |
| 0 | 3917.5 group | | .... | .. |
| 00 | 3919.1 | 6 lines, | .... | .. |
| 00 | 3922.3 | intensities > 2 | .... | .. |
| K 10 | 3933.8 | 3933.825 | *Ca* | 1000 |
| 1 | 3944.6 | 3944.160 | *Al* | 15 |
| 0 | 3948.3 group | 8 lines, intensities | .... | .. |
| 0 | 3952.1 | 2 and greater | .... | .. |
| | | 3960.422 | *Fe* | 4 |
| 0 Triple | 3961.3 | 3961.281 | *Fe* | 3 |
| | | 3961.674 | *Al* | 20 |
| H 10 | 3969.0 | 3968.625 | *Ca* | 700 |
| | | 3970.177 | *He* | .. |
| | | 3981.917 | *Ti* | 4 |
| 1 Triple | 3982.5 | 3982.630 | *Ti–Mn* | 2 |
| | | 3982.742 | *Y* | 3 |
| 0 *d?* | 3989.0 | 3989.137 | —— | 3 |
| | | 3989.232 | —— | 2 |
| 0 | 3991.0 | 3991.333 | *Cr, Zr* | 3 |
| 1 | 3995.5 group | 6 lines, intensities | .... | .. |
| 1 | 3998.3 | 3 and greater | .... | .. |
| 1 *d* | 4004.9 | 4003.912 | *Ce–Fe–Ti* | 3 |
| | | 4005.408 | *Fe* | 7 |
| 1 | 4006.0 | 4005.856 | —— | 3 |
| 0 *d* | 4009.1 | 4009.079 | *Ti* | 3 |
| 1 | 4012.4 | 4012.541 | *Ti* | 4 |
| 00 | 4018.1 | 4018.234 | *Mn* | 3 |
| | | 4018.269 | *Mn* | 4 |
| 1 | 4021.9 | 4022.018 | *Fe* | 5 |
| 4 | 4026.0 | (4026.342) | *He* | .. |
| 0 | 4028.4 | 4028.497 | *Ti–* | 4 |
| 1 | 4030.8 | 4030.878 | *Mn* | 4 |
| | | (4030.918) | .... | .. |
| | | 4030.947 | *Mn* | 5 |

TABLE I.—*Continued.*

| Flash Intensity | Wave-length | Rowland | Substance | Solar Intensity |
|---|---|---|---|---|
| 0 | 4032.0 | 4031.942 | *Mn* | 2 |
| 1 | 4033.3 | 4033.224 | *Fe–Mn* | 7 *d ?* |
| 1 | 4034.6 | 4034.644 | *Mn–Fe* | 6 *d ?* |
| 0 | 4035.7 | 4035.883 | *Mn* | 4 *d ?* |
| 2 | 4045.9 | 4045.975 | *Fe* | 30 |
| 0 | 4047.8 | ........ | .... | .. |
| 00 | 4048.9 | 4048.910 | *Mn–Cr* | 5 |
| 0 *d?* | 4049.7 | 4049.716 | —— | 1 *N d ?* |
| 0 | 4052.0 } group | Intensities 2 and | .... | .. |
| 0 | 4055.7 } | greater. 10 lines | .... | .. |
| 00 | 4058.3 | 4058.372 | *Co–Fe* | 4 |
| 2 | 4063.5 | 4063.759 | *Fe* | 20 |
| 1 | 4066.6 | ........ | .... | .. |
| 0 | 4069.3 | 4069.221 | —— | 2 |
| 2 | 4072.0 | 4071.908 | *Fe* | 15 |
| 6 | 4077.7 | 4077.885 | *Sr* | 8 |
| 00 | 4083.1 } group | 7 lines. Intensities | .... | .. |
| 00 | 4087.2 } | 2 and greater | .... | .. |
| *Hδ* 10 | 4102.0 | 4102.000 | *Hδ* | .. |
| 0 | 4107.7 | 4107.649 | *Ce–Fe–Zr* | 5 |
| 0 Triple | 4109.5 | 4108.687 | —— | 2 |
| | | 4109.215 | *Fe* | 3 |
| | | 4109.905 | *V* | 2 |
| | | 4109.953 | *Fe* | 3 |
| 0 | 4118.7 | 4118.708 | *Fe* | 5 |
| | | 4118.934 | *Co* | 4 |
| 0 | 4121.4 | 4121.477 | *Cr–Co* | 6 *d ?* |
| 0 | 4123.2 | 4123.384 | *La* | 12 |
| 0 | 4127.7 } group | 16 lines. | .... | .. |
| | | Intensities | .... | .. |
| 0 | 4134.8 } | 2 and greater | .... | .. |
| 1 *d* | 4137.3 | 4137.156 | *Fe* | 6 |
| | | 4137.567 | —— | 2 |
| 0 *d* | 4140.3 | 4140.089 | *Fe* | 6 |
| | | 4140.558 | —— | 3 |
| 0 | 4142.0 | 4142.025 | *Fe* | 4 |
| 2 *d?* | 4144.0 | (4143.919) | *He* | .. |
| | | 4144.038 | *Fe* | 15 |
| 0 | 4146.3 | 4146.225 | *Fe* | 3 |
| 00 | 4147.9 | 4147.836 | *Fe* | 4 |
| 1 *d* | 4149.3 | ........ | .... | .. |
| 0 | 4149.9 | ........ | .... | .. |
| 00 | 4152.3 | 4152.343 | *Fe* | 3 |
| 1 | 4154.1 | 4154.071 | *Fe* | 4 |
| 1 | 4156.2 | ........ | .... | .. |
| 0 | 4156.4 | ........ | .... | .. |
| 0 | 4157.5 | ........ | .... | .. |
| 0 | 4161.7 | 4161.682 | —— | 4 |
| 1 | 4163.8 | 4163.818 | *Ti, Cr–* | 4 |
| 1 | 4167.0 } | 4167.438 | —— | 8 |
| 1 | 4167.9 } | | | |
| 0 | 4168.7 | ........ | .... | .. |

TABLE I.—*Continued.*

| Flash Intensity | Wave-length | Rowland | Substance | Solar Intensity |
|---|---|---|---|---|
| | | 4171.213 | *Ti*— | 4 |
| 2 | 4171.6 | 4171.854 | *Cr*, *La*, *Mn*, *Ni*, *Fe* | 2 |
| | | 4172.066 | *Ti*, *Fe* | 2 |
| 1 | 4172.4 | ........ | .... | .. |
| 1 | 4173.6 | 4173.624 | —— | 3 |
| | | 4173.710 | —— | 3 |
| 0 | 4175.3 | 4175.082 | *Fe* | 4 |
| 0 | 4175.8 | 4175.806 | *Fe* | 5 |
| 0 | 4176.5 | 4176.739 | *Fe*–*Mn* | 5 |
| 1 | 4177.3 | 4177.698 | *Fe* | 3 |
| | group | 4177.772 | —— | 3 |
| | | 4178.223 | —— | 2 |
| 1 | 4179.1 | 4179.025 | —— | 3 |
| 0 *d*? | 4180.3 | ........ | .... | .. |
| 0 | 4181.8 | 4181.919 | *Fe* | 5 |
| 0 | 4184.4 | ........ | .... | .. |
| 00 | 4186.2 | 4186.280 | *Ti* | 1 |
| 0 | 4187.2 | 4187.204 | *Fe* | 6 |
| 0 | 4187.9 | 4187.943 | *Fe* | 5 |
| | | 4188.019 | —— | 3 |
| 0 | 4188.9 | 4188.894 | —— | 4 |
| 0 *d* | 4191.7 | 4191.595 | *Fe* | 6 |
| | | 4191.843 | *Fe* | 3 |
| 0 | 4193.0 | ........ | .... | .. |
| 0 | 4194.0 | ........ | .... | .. |
| 0 | 4195.3 | 4195.492 | *Fe* | 5 |
| 1 | 4198.6 | 3 lines, 2 *Fe* | .... | 4, 4, 3 |
| 1 | 4199.2 | 4199.267 | *Zr*–*Fe* | 5 |
| | | 4200.761 | —— | 1 |
| 00 Triple | 4200.8 | 4200.946 | *Ti* | 1 |
| | | 4201.089 | *Fe* | 3 |
| 1 | 4202.2 | 4202.198 | *Fe* | 8 |
| 00 | 4204.0 | 4204.101 | *Fe* | 3 |
| 00 | 4204.9 | 4204.916 | —— | 2 |
| 0 | 4205.5 | ........ | .... | .. |
| 00 | 4206.1 | .... ... | .... | .. |
| 0 | 4206.8 | 4206.862 | *Fe* | 3 |
| 0 | 4207.7 | ........ | .... | .. |
| 0 | 4208.6 | 4208.766 | *Fe* | 3 |
| 0 | 4209.1 | 4209.144 | *Zr* | 1 |
| 0 | 4209.9 | 4209.985 | *V* | 1 |
| 0 | 4210.5 | 4210.494 | *Fe* | 4 |
| | | 4210.561 | —— | 3 |
| 0 | 4211.2 | 4211.127 | —— | 3*N* |
| 00 | 4212.0 | 4212.048 | *Zr*– | 2 |
| 00 | 4212.8 | 4212.801 | *Cr*? | 3*r* |
| 00 | 4213.7 | 4213.812 | *Fe* | 3 |
| 8 | 4215.7 | 4215.703 | *Sr* | 5 *d*? |
| 0 *d*? | 4217.8 | 4217.720 | *La*, *Fe*–*Cr* | 5 *d*? |
| 00 | 4219.5 | 4219.516 | *Fe* | 4 |
| | | 4219.580 | —— | 3 |
| 0 *d*? | 4220.3 | 4220.509 | *Fe* | 3 |

TABLE I.—*Continued.*

| Flash Intensity | Wave-length | Rowland | Substance | Solar Intensity |
|---|---|---|---|---|
| 0 *d?* | 4222.7 | ........ | .... | .. |
| 0 | 4223.4 | ........ | .... | .. |
| 0 | 4224.5 | { 4224.337<br>4224.673 | *Fe*<br>*Cr–Fe* | 4<br>3 |
| 0 *d?* | 4225.6 | 4225.619 | *Fe* | 3 |
| *g* 3 | 4226.9 | 4226.904 | *Ca* | 20 *d ?* |
| 0 | 4231.1 | 4231.183 | *Ni* | 4 *N* |
| 3 | 4233.2 | 4233.328 | *Mn–Fe* | 4 |
| 0 | 4235.4 | { 4235.298<br>4235.450 | *Mn*<br>*Mn* | 2<br>3 |
| 2 | 4235.8 | 4236.112 | *Fe* | 8 |
| 00 | 4237.2 | 4237.339 | *Fe* | 3 |
| 1 | 4238.0 | ........ | .... | .. |
| 1 *d* | 4239.9 | { 4239.890<br>4240.014 | *Mn*<br>*Fe* | 3<br>3 |
| 1 *d ?* | 4243.1 | ........ | .... | .. |
| 4 | 4247.0 | 4246.996 | *Sc?* | 5 |
| 1 *d* | 4248.7 | ........ | .... | .. |
| 2 | 4250.3 | 4250.287 | *Fe* | 8 |
| 2 | 4251.1 | 4250.945 | *Fe* | 8 |
| 1 | 4253.1 | ........ | .... | .. |
| 3 | 4254.4 | 4254.505 | *Cr* | 8 |
| 0 *d* | 4255.9 | ........ | .... | .. |
| 0 | 4256.7 | ........ | .... | .. |
| 1 | 4258.4 | ........ | .... | .. |
| 0 *d ?* | 4259.5 | ........ | .... | .. |
| 2 | 4260.6 | 4260.640 | *Fe* | 10 |
| 0 | 4262.2 | ........ | .... | .. |
| 1 *d* | 4263.9 | ........ | .... | .. |
| 0 *d ?* | 4266.8 | ........ | .... | .. |
| 0 *d* | 4267.8 | ........ | .... | .. |
| 1 | 4269.8 | ........ | .... | .. |
| 1 | 4271.3 | 4271.325 | *Fe* | 6 |
| 3 | 4271.9 | 4271.934 | *Fe* | 15 |
| 1 *d ?* | 4273.5 | { 4273.482<br>4273.643 | *Fe*<br>*Zr* | 3 *N*<br>2 *N* |
| 1 | 4274.3 | 4274.348 | —— | 2 *N* |
| 3 | 4274.9 | 4274.958 | *Cr* | 7 *d ?* |
| 1 *d* | 4277.0 | { 4276.836<br>4277.147 | *-Zr*<br>*V-* | 2<br>1 *N* |
| 00 | 4278.3 | 4278.390 | *Fe–Ti* | 3 |
| 0 | 4279.8 | 4279.874 | —— | 2 *N d ?* |
| 0 | 4281.2 | 4281.257 | *Mn* | 2 |
| 1 | 4282.1 | 4282.127 | —— | 2 *N* |
| 1 | 4282.6 | 4282.565 | *Fe* | 5 |
| 1 | 4286.1 | 4286.168 | *Ti-* | 2 |
| 1 | 4287.8 | 4288.038 | *Ti* | 2 |
| 0 | 4288.5 | ........ | .... | .. |
| 2 | 4289.9 | 4289.885 | *Cr* | 5 |
| 1 | 4291.1 | 4291.114 | *Ti* | 3 |
| 1 | 4292.1 | ........ | .... | .. |
| 1 *d ?* | 4293.3 | ........ | .... | .. |

TABLE I. — *Continued.*

| Flash Intensity | Wave-length | Rowland | Substance | Solar Intensity |
|---|---|---|---|---|
| 2 | 4294.2 | { 4294.204<br>{ 4294.301 | *Ti*<br>*Fe* | 2<br>5 |
| 0 | 4295.3 | 4295.383 | —— | 3 *Nd ?* |
| 0 | 4296.1 | 4295.914 | *Cr, Ti* | 2 |
| 2 | 4296.7 | 4296.735 | —— | 3 |
| 0 | 4298.9 | 4298.828 | *Ti* | 2 |
| 2 *d* | 4299.6 | { 4299.410<br>{ 4299.803 | *Ti, Fe*<br>*Ti* | 4<br>2 |
| 3 | 4300.4 | { 4300.211<br>{ 4300.732 | *Ti*<br>*Ti* | 3<br>2 |
| 0 | 4301.3 } Group | 8 lines. Intensities 2 and greater | .... | .. |
| 2 *d* | 4302.4 } Group | | .... | .. |
| 1 *d* | 4303.5 } Group | | .... | .. |
| 1 | 4304.1 | 4304.098 | —— | 4 |
| 1 | 4304.6 | ........ | .... | .. |
| 2 | 4305.9 | 4306.078 | *Ti* | 4 |
| 2 | 4306.9 | ........ | .... | .. |
| G 3 | 4307.9 | { 4307.907<br>{ 4308.081 | *Ca*<br>*Fe* | 3<br>6 |
| 2 *d* | 4309.4 | ........ | .... | .. |
| 2 *d* | 4312.3 | { 4312.247<br>{ 4312.462 | ——<br>—— | 2<br>2 |
| 3 | 4312.9 | 4313.034 | *Ti* | 3 |
| 3 | 4314.2 | 4314.248 | *Sc* | 3 |
| 3 | 4315.2 | { 4315.138<br>{ 4315.262 | *Ti*<br>*Fe* | 3<br>4 |
| 1 | 4317.2 | ........ | .... | .. |
| 1 | 4318.9 | 4318.817 | *Ca, Mn?* | 4 |
| 3 | 4320.9 | 4320.907 | *Sc* | 3 |
| 1 | 4323.9 | 4324.007 | —— | 3 |
| 3 | 4325.0 | 4325.152 | *Sc* | 4 |
| 3 | 4326.0 | 4325.939 | *Fe* | 8 |
| 0 | 4427.2 | 4327.274 | *Fe* | 3 |
| 0 | 4328.4 | ........ | .... | .. |
| 0 | 4329.7 | ........ | .... | .. |
| 2 | 4330.9 | 4330.866 | *Ti, Ni* | 2 |
| 0 | 4331.8 | ........ | .... | .. |
| 1 | 4332.6 | ........ | .... | .. |
| 2 | 4334.2 | ........ | .... | .. |
| 0 | 4335.1 | ........ | .... | .. |
| 0 | 4336.1 | ........ | .... | .. |
| 2 *d* | 4337.3 | { 4337.216<br>{ 4337.725 | *Fe*<br>*Cr* | 5<br>3 |
| $H\gamma$ 10 | 4340.6 | 4340.634 | *H* | 20 *N* |
| 0 | 4343.9 | 4343.861 | *Fe* | 2 |
| 2 *d ?* | 4344.5 | { 4344.451<br>{ 4344.670 | *Ti*–<br>*Cr* | 2<br>4 |
| 00 | 4347.0 | 4346.987 | *Cr* | 1 |
| 0 *d* | 4347.6 | { 4347.403<br>{ 4347.705 | *Fe*<br>—— | 1<br>1 *N* |
| 3 | 4351.3 | 4351.216 | *Cr* | 3 |
| 4 | 4352.0 | 4351.930 | *Co* | 5 |

TABLE I.—*Continued.*

| Flash Intensity | Wave-length | Rowland | Substance | Solar Intensity |
|---|---|---|---|---|
| 2 | 4353.1 | 4352.908 | *Fe* | 4 |
| 2 | 4354.4 | ........ | .... | .. |
| 2 | 4355.2 | ........ | .... | .. |
| 2 | 4358.7 | ........ | .... | .. |
| 2 | 4359.8 | 4359.874 | *Cr* | 3 |
| 1 | 4360.6 | 4360.644 | *Ti* | 1 |
| 1 *d* | 4363.2 | ........ | .... | .. |
| 1 | 4363.9 | ........ | .... | .. |
| 0 | 4364.7 | ........ | .... | .. |
| 2 *d* | 4367.9 | 4367.749<br>4367.839 | *Fe*<br>*Ti* | 5<br>2 |
| 1 | 4369.3 | ........ | .... | .. |
| 2 | 4369.9 | 4369.941 | *Fe* | 4 |
| 1 | 4371.1 | ........ | .... | .. |
| 2 | 4374.7 | 4374.628 | *Sc, Fe ?* | 3 |
| 2 | 4375.3 | 4375.103 | *V, Mn* | 2 |
| 2 | 4376.2 | 4376.107 | *Fe* | 6 |
| 1 | 4377.3 | 4377.388 | —— | 2 *N* |
| 0 | 4378.4 | 4378.419 | —— | 2 *N d ?* |
| 2 | 4379.4 | 4379.396 | *V* | 4 |
| 0 | 4381.2 | 4381.274 | *Cr* | 0 |
| 4 | 4383.7 | 4383.720 | *Fe* | 15 |
| 2 | 4384.6 | 4384.873 | *V* | 3 |
| 2 | 4385.5 | 4385.548 | —— | 2 |
| 1 | 4387.0 | 4387.007 | *Ti ?* | 1 |
| 1 | 4388.5 | 4388.571 | *Fe* | 3 |
| 0 | 4389.4 | 4389.413 | *Fe–* | 2 |
| 0 | 4390.1 | 4390.149 | *V* | 2 |
| 1 | 4391.0 | 4391.123<br>4391.192 | *Fe*<br>*Ti* | 2<br>1 |
| 1 | 4391.9 | 4391.924 | *Cr* | 1 |
| 5 | 4395.3 | 4395.201<br>4395.413 | *Ti*<br>*V, Zr* | 3<br>2 |
| 1 | 4397.9 | ........ | .... | .. |
| 2 | 4399.8 | 4399.935 | *Ti, Cr* | 3 |
| 2 | 4400.6 | 4400.555 | *Sc* | 3 |
| 0 | 4401.5 | 3 lines | *Fe, Fe, Ni* | 2, 1, 2 |
| 3 | 4404.8 | 4404.927 | *Fe* | 10 |
| 1 | 4407.9 | 4407.810<br>4407.871 | *V*<br>*Fe* | 2<br>4 |
| 2 | 4408.8 | 4408.364<br>4408.582<br>4408.683 | *V*<br>*Fe*<br>*V* | 2<br>3<br>2 |
| 2 *d ?* | 4411.0 | ........ | .... | .. |
| 1 | 4412.0 | ........ | .... | .. |
| 3 *d ?* | 4415.3 | 4415.293 | *Fe* | 8 |
| 3 | 4417.2 | ........ | .... | .. |
| 3 | 4418.0 | 4417.884 | *Ti–* | 3 |
| 0 | 4422.1 | ........ | .... | .. |
| 2 | 4422.9 | 4422.741 | *Fe, Y* | 3 |
| 1 *d ?* | 4424.6 | ........ | .... | .. |
| 0 *d* | 4425.7 | 4425.608 | *Ca* | 4 |

TABLE I.— *Continued.*

| Flash Intensity | Wave-length | Rowland | Substance | Solar Intensity |
|---|---|---|---|---|
| 3 | 4427.7 | 4427.482 | *Fe* | 5 |
| 1 | 4430.3 | ......... | .... | .. |
| 1 | 4430.7 | 4430.785 | *Fe* | 3 |
| 2 *d* | 4435.4 | 4435.129 | *Ca* | 5 |
| | | 4435.851 | *Ca* | 4 |
| 0 | 4436.5 | 4436.516 | *Mn* | 2 |
| 0 | 4438.0 | ......... | .... | .. |
| 1 | 4441.7 | 4441.881 | *V*– | 3 *Nd?* |
| 1 | 4442.7 | 4442.510 | *Fe* | 6 |
| 5 | 4444.0 | 4443.976 | *Ti* | 5 |
| 1 | 4445.8 | ......... | ... | .. |
| 1 *d?* | 4447.5 | 4447.302 | *Mn, Fe* | 2 |
| | | 4447.892 | *Fe* | 6 |
| 1 | 4448.3 | ........ | .... | .. |
| 1 *d?* | 4449.6 | 4449.313 | *Ti* | 2 |
| 3 | 4450.6 | 4450.654 | *Ti?* | 2 |
| 1 | 4452.0 | 4451.752 | *Mn* | 3 |
| 1 *d* | 4453.4 | 4453.486 | *Ti* | 2 |
| 1 | 4454.2 | ......... | .... | .. |
| 3 | 4455.0 | 4454.953 | *Ca, Zr* | 5 |
| 00 | 4456.0 | 4555.980 | *Mn* | 2 |
| 0 *d* | 4457.8 | 4457.600 | *Ti, V, Zr* | 2 |
| | | 4457.712 | *Mn* | 2 |
| 1 | 4459.1 | 4459.199 | *Ni* | 2 |
| 0 | 4460.4 | 4460.462 | *Mn* | 1 |
| 2 | 4461.8 | 4461.818 | *Fe* | 4 |
| 1 | 4463.3 | ......... | .... | .. |
| 2 | 4464.7 | 4464.617 | *Ti?* | 2 |
| | | 4464.844 | *Mn* | 2 |
| 1 | 4466.7 | 4466.727 | *Fe* | 5 |
| 3 | 4468.7 | 4468.663 | *Ti*– | 5 |
| 8 | 4471.6 | (4471.646) | *He* | .. |
| 0 | 4473.3 | ......... | .... | .. |
| 1 | 4476.3 | 4476.185 | *Fe* | 4 |
| 1 | 4479.8 | ......... | .... | .. |
| 0 | 4482.3 | 4482.338 | –,*Fe* | 5 |
| | | 4482.438 | *Fe* | 3 |
| 1 | 4483.0 | 4482.904 | *Ti–Fe* | 1 |
| 0 | 4484.4 | 4484.392 | *Fe* | 4 |
| 0 | 4486.2 | ......... | .... | .. |
| 1 | 4489.3 | 4489.351 | —— | 2 |
| 0 | 4490.2 | 4490.253 | *Mn–Fe* | 3 *N* |
| 1 wide | 4491.7 | 4491.570 | —— | 2 |
| | | 4491.823 | *Cr, Mn* | 0 |
| 1 | 4494.7 | 4494.738 | *Fe* | 6 |
| 1 | 4497.0 | 4497.023 | *Cr* | 3 |
| 0 | 4499.1 | 4499.066 | *Mn* | 1 |
| 3 | 4501.4 | 4501.448 | *Ti*,– | 5 |
| 3 | 4508.5 | 4508.455 | *Fe?*– | 4 |
| 2 | 4515.6 | 4515.508 | —— | 3 |
| 1 | 4517.7 | 4517.702 | *Fe* | 3 |
| 1 | 4518.2 | 4518.198 | *Ti* | 3 |

TABLE I.—*Continued.*

| Flash Intensity | Wave-length | Rowland | Substance | Solar Intensity |
|---|---|---|---|---|
| 2 | 4520.3 | 4520.397 | *Fe ?–* | 3 |
| 3 | 4522.9 | 4522.802 | —— | 3 |
| | | 4522.974 | *Ti* | 2 |
| 0 | 4525.0 | 4525.314 | *Fe* | 5 |
| 1 | 4527.5 | 4527.490 | *Ti* | 3 |
| 1 | 4529.2 | ........ | .... | .. |
| 1 | 4531.4 | 4531.327 | *Fe* | 5 |
| 5 | 4534.1 | 4534.139 | *Ti–Co* | 6 |
| 1 *d* | 4535.9 | 4535.741 | *Ti* | 3 |
| | | 4536.094 | *Ti* | 2 |
| | | 4536.222 | *Ti* | 2 |
| 0 | 4539.7 | ........ | .... | .. |
| 1 wide | 4541.8 | 4541.690 | *Cr* | 2 |
| 0 | 4544.9 | 4544.864 | *Ti* | 3 |
| 0 | 4546.1 | 4546.129 | *Fe, Cr* | 3 |
| 5 | 4549.9 | 4549.808 | *Ti–Co* | 6 *d ?* |
| 5 | 4554.2 | 4554.211 | *Ba* | 8 |
| 2 | 4556.2 | 4556.306 | *Fe–Cr* | 4 |
| 2 | 4558.8 | 4558.827 | *Co ?* | 3 |
| 1 | 4560.6 | ........ | .... | .. |
| 5 | 4563.8 | 4563.939 | *Ti* | 4 |
| 0 | 4566.0 | 4565.842 | *Co–Fe* | 2 |
| 6 | 4572.2 | 4572.156 | *Ti–* | 6 |
| 0 | 4575.0 | 4574.899 | *Fe* | 2 |
| 1 | 4576.6 | 4576.512 | —— | 2 |
| 00 | 4580.2 | 4580.228 | *Cr* | 3 |
| 4 | 4584.0 | 4584.018 | *Fe–* | 4 |
| 1 | 4586.4 | 4586.408 | *Cr* | 1 |
| | | 4586.552 | *V* | 1 |
| 1 | 4588.2 | 4588.381 | —— | 3 |
| 2 | 4590.1 | 4590.126 | —— | 3 |
| 1 | 4592.7 | 4592.707 | *Ni* | 2 |
| | | 4592.840 | *Fe* | 4 |
| 0 | 4593.8 | ........ | .... | .. |
| 0 | 4594.3 | 4594.297 | *V* | 2 *N* |
| 0 | 4595.7 | ........ | .... | .. |
| 0 | 4596.2 | 4596.245 | *Fe* | 2 |
| 0 | 4598.3 | 4598.303 | *Fe* | 3 |
| 2 | 4600.2 | ........ | .... | .. |
| 2 | 4601.0 | 4600.932 | *Cr* | 3 |
| 1 | 4602.1 | 4602.183 | *Fe* | 3 |
| 1 | 4603.1 | 4603.126 | *Fe* | 6 |
| 1 | 4607.7 | 4607.831 | *Fe* | 4 |
| 1 *d ?* | 4611.3 | 4611.368 | *Cr* | 0 |
| | | 4611.469 | *Fe* | 5 |
| 2 *d* | 4613.5 | 4613.386 | *Fe* | 3 |
| | | 4613.544 | *Cr, La* | 3 |
| 1 | 4615.8 | ........ | .... | .. |
| 1 | 4616.4 | 4616.305 | *Cr* | 4 |
| 2 | 4619.1 | 4618.971 | *Fe–* | 4 *d ?* |
| 0 | 4619.9 | 4619.711 | *Cr* | 1 |
| 1 | 4620.6 | ........ | .... | .. |

TABLE I — *Continued.*

| Flash Intensity | Wave-length | Rowland | Substance | Solar Intensity |
|---|---|---|---|---|
| 1 | 4622.0 | 4622.065 | *Cr* | 0 |
| | | 4622.128 | *Cr* | 1 |
| 1 | 4622.7 | 4622.627 | *Cr* | 1 |
| 1 | 4623.4 | 4623.279 | *Ti* | 2 |
| 1 | 4625.2 | 4625.227 | *Fe* | 5 |
| 2 | 4626.4 | 4626.358 | *Cr* | 5 |
| 1 | 4627.7 | ......... | .... | .. |
| 3 | 4629.5 | 4629.521 | *Ti–Co* | 6 |
| 0 | 4630.2 | 4630.306 | *Fe* | 4 |
| 2 | 4634.2 | 4034.254 | —— | 2 |
| 0 | 4636.2 | ......... | .... | .. |
| 2 | 4637.7 | 4637.685 | *Fe* | 5 |
| 2 *d* | 4639.8 | 3 *Ti* lines | .... | 2, 2, 1 |
| 2 | 4646.3 | 4646.347 | *Cr* | 5 |
| 1 | 4647.7 | 4647.617 | *Fe* | 4 |
| 1 | 4648.9 | 4648.835 | *Ni* | 4 |
| 2 *d* | 4651.9 | 4651.461 | *Cr* | 4 |
| | | 4652.343 | *Cr* | 5 |
| 2 *d* | 4654.7 | 4654.672 | *Fe* | 4 |
| | | 4654.800 | *Fe* | 5 |
| 1 | 4656.5 | 4656.644 | *Ti* | 3 |
| 2 | 4657.3 | 4657.380 | *Ti?* | 2 |
| 1 | 4662.4 | ......... | .... | .. |
| 1 | 4663.8 | ......... | .... | .. |
| 2 | 4667.4 | 4667.626 | *Fe* | 4 |
| | | 4667.768 | *Ti* | 3 |
| 2 | 4670.3 | ......... | .... | .. |
| 0 | 4678.4 | ......... | .... | .. |
| 1 *d?* | 4680.4 | ......... | .... | .. |
| 2 | 4682.6 | ......... | .... | .. |
| 2 | 4685.3 | 4685.452 | *Ca* | 2 *N* |
| 0 | 4691.6 | 4691.602 | *Fe* | 5 |
| 0 | 4698.6 | 3 lines, 2 *Cr*, 1 *Ti* | .... | 1, 1, 1 |
| 0 | 4700.3 | 4700.337 | —— | 4 |
| 0 | 4701.3 | .... | .... | .. |
| 1 | 4702.9 } group | 4703.177 | *Mg* | 10 |
| 1 | 4704.8 } group | 4703.994 | *Ni* | 3 |
| | | 4705.131 | *Fe* | 4 |
| 1 | 4707.4 } group | 6 lines, intensities | .... | .. |
| 1 | 4710.0 } group | 2 and greater | .... | .. |
| 3 | 4713.3 | (4713.252) | *He* | .. |
| 1 | 4714.7 | 4714.599 | *Ni* | 6 |
| 1 wide | 4727.9 | 4727.582 | *Fe* | 3 |
| | | 4727.676 | *Mn* | 2 |
| | | 4728.732 | *Fe* | 4 |
| 2 | 4731.6 | 4731.651 | *Fe?* | 4 |
| 00 | 4733.6 | 4733.779 | *Fe* | 4 |
| 2 | 4737.0 | 4736.963 | *Fe* | 6 |
| 1 *d* | 4740.9 | ......... | .... | .. |
| 00 | 4746.0 | 4745.992 | *Fe* | 4 |
| 0 | 4748.8 | .... ... | .... | .. |
| 1 | 4761.8 } group | 5 lines. Intensities | 4 *Mn*, 1 *Ti* | .. |
| 1 | 4766.6 } group | 3 and greater | | |

TABLE I — *Continued.*

| Flash Intensity | Wave-length | Rowland | Substance | Solar Intensity |
|---|---|---|---|---|
| 1 *d?* | 4768.5 | { 4768.519 | —— | 3 |
| | | { 4768.595 | *Fe* | 2 |
| 1 | 4771.4 | 4771.664 | ←— | 3 |
| 1 | 4773.0 | 4773.007 | *Fe* | 4 |
| 00 | 4776.7 | ........ | .... | .. |
| 2 | 4780.2 | 4780.169 | *Co* | 2 |
| 2 | 4783.7 | 4783.613 | *Mn* | 6 |
| 2 | 4786.8 | { 4786.727 | *Ni* | 3 |
| | | { 4787.003 | *Fe* | 2 |
| 2 | 4789.5 | 4789.528 | *Cr* | 2 |
| 1 | 4792.6 | 4792.702 | *Ti–Cr* | 2 |
| 2 | 4805.4 | 4805.285 | —— | 3 |
| 00 | 4810.9 | 4810.724 | *Zn* | 3 |
| 2 | 4824.0 | { 4823.697 | *Mn* | 5 |
| | | { 4824.325 | *Fe* | 3 |
| 1 wide | 4840.4 | 4 lines | .... | 3, 2, 3, 3 |
| 00 | 4843.8 | ........ | .... | .. |
| 1 | 4848.4 | 4848.438 | —— | 2 |
| 2 | 4855.6 | ........ | .... | .. |
| *Hβ* 10 | 4861.5 | 4861.527 | *H* | 30 |
| 2 | 4867.7 | ........ | .... | .. |
| 2 | 4871.2 | ........ | .... | .. |
| 1 | 4890.7 | 4890.948 | *Fe* | 6 |
| 1 | 4891.6 | 4891.683 | *Fe* | 8 |
| 2 | 4899.7 | ........ | .... | .. |
| 0 wide | 4903.4 | 4903.502 | *Fe* | 5 |
| 0 wide | 4910.4 | 4 *Fe* lines | .... | 2, 3, 2, 2 |
| 1 | 4918.2 | ........ | .. | .. |
| 1 | 4920.2 | 4920.685 | *Fe* | 10 |
| 3 | 4924.1 | 4924.107 | *Fe* | 5 |

In comparing wave-lengths of the flash spectrum with those of the solar spectrum, it is necessary to bear in mind two points: first, we are dealing with a dispersion of about one-fifth of Rowland's, with the focus not so exact, and therefore it will be impossible to separate in the flash the counterparts of close dark solar lines; second, the emission and absorption lines are formed at different heights above the Sun's surface, and the emission lines will, as a result, be shifted (in this flash) towards the violet.

The focus is best between F and H, and for the present purpose this region only will be considered. Neglecting *H* and *He* lines and those lines identified with groups, 374 lines were measured in the flash between F and H. Ninety-one of these were

unidentified, and 283 were identified with lines in the solar spectrum.

The results of these comparisons are put down in Table II, arranged according to their intensities (scale 0–10.)

TABLE II.

LINES IN THE FLASH BETWEEN F AND H.

Scale 0–10.

| Element | ∞ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Total | Average Intensity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Fe* | 11 | 39 | 37 | 28 | 8 | 2 | — | — | — | — | 125 | 1.70 |
| *Ti* | 2 | 7 | 22 | 15 | 10 | — | 5 | 1 | — | — | 62 | 1.84 |
| *Cr* | 3 | 9 | 10 | 12 | 3 | 1 | — | — | — | — | 38 | 1.24 |
| *Mn* | 4 | 9 | 9 | 4 | 1 | — | — | — | — | — | 27 | 0.74 |
| *V* | — | 5 | 4 | 5 | — | — | 1 | — | — | — | 15 | 1.27 |
| *Zr* | 1 | 3 | 3 | — | 1 | — | 1 | — | — | — | 9 | 1.22 |
| *Ni* | — | 1 | 6 | 2 | — | — | — | — | — | — | 9 | 1.11 |
| *Ca* | — | 1 | 1 | 3 | 3 | — | — | — | — | — | 8 | 2.00 |
| *Sc* | — | — | — | 2 | 3 | 1 | — | — | — | — | 6 | 2.83 |
| *Co* | 2 | 2 | 1 | 1 | — | — | — | — | — | — | 6 | 0.50 |
| *Y* | — | — | 1 | 1 | — | — | — | — | — | — | 2 | 1.50 |
| *La* | — | 2 | — | 1 | — | — | — | — | — | — | 3 | 0.67 |
| *Sr* | — | — | — | — | — | — | — | 1 | — | 1 | 2 | 7.00 |
| *Ba* | — | — | — | — | — | — | 1 | — | — | — | 1 | 5.00 |
| *Mg* | — | — | 1 | — | — | — | — | — | — | — | 1 | 1.00 |
| *Zn* | 1 | — | — | — | — | — | — | — | — | — | 1 | 0 |
| *Ce* | 1 | — | 1 | — | — | — | — | — | — | — | 2 | 0.50 |
| —— | 4 | 16 | 17 | 8 | 1 | — | — | — | — | — | 46 | 0.78 |
| Unidentified | 3 | 37 | 39 | 11 | 1 | — | — | — | — | — | 91 | 0.70 |
| Total | 32 | 131 | 152 | 93 | 31 | 4 | 8 | 2 | 0 | 1 | 454 | |

In the column of Elements, — means that these lines are unidentified in Rowland's tables.

(The total includes eighty lines identified with more than one element, either in Rowland's tables or in the comparisons between flash and solar spectra.) The average intensities are given in the last column.

Two points are immediately noticed in comparing the two spectra: first, for each and every element, the brighter the solar line the brighter the flash line corresponding to it; second, the intensities of the solar lines which correspond to a line of given

brightness in the flash differ with different metals. *Fe* and *Ni* lines of intensity 5, *Ti*, *Sc*, and *V* lines of intensity 2 are identified with flash lines of equal strength. These differences for the various elements were so marked that in order to arrive at their significance, and hence draw some conclusions regarding the "reversing layer," comparisons were made between the flash and the solar spectrum.

The 283 lines identified with lines in Rowland's tables are arranged according to their intensities (scale 1–1000), in Table III.

TABLE III.

SOLAR LINES WITH WHICH THE FLASH LINES WERE IDENTIFIED.

Scale 1–1000.

| Element | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 10 | 12 | 15 | 20 | 30 | Total | Average Intensity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Fe* | — | 3 | 11 | 28 | 33 | 22 | 12 | 2 | 6 | 2 | — | 4 | 1 | 1 | 125 | 4.92 |
| *Ti* | — | 11 | 23 | 13 | 8 | 3 | 4 | .. | .. | .. | .. | .. | .. | .. | 62 | 2.69 |
| *Cr* | 4 | 8 | 3 | 13 | 3 | 4 | 1 | 1 | 1 | .. | .. | .. | .. | .. | 38 | 2.27 |
| *Mn* | — | 3 | 9 | 5 | 5 | 3 | 2 | .. | .. | .. | .. | .. | .. | .. | 27 | 3.08 |
| *V* | — | 5 | 8 | 1 | 1 | .. | .. | .. | .. | .. | .. | .. | .. | .. | 15 | 1.87 |
| *Zr* | — | 1 | 5 | 1 | — | 2 | .. | .. | .. | .. | .. | .. | .. | .. | 9 | 2.67 |
| *Ni* | — | — | 4 | 2 | 2 | — | 1 | .. | .. | .. | .. | .. | .. | .. | 9 | 3.11 |
| *Ca* | — | — | 1 | 1 | 3 | 2 | .. | .. | .. | .. | .. | .. | 1 | .. | 8 | 5.88 |
| *Sc* | — | — | — | 4 | 1 | 1 | .. | .. | .. | .. | .. | .. | .. | .. | 6 | 3.50 |
| *Co* | .. | .. | 2 | 1 | 2 | 1 | .. | .. | .. | .. | .. | .. | .. | .. | 6 | 2.67 |
| *Y* | .. | .. | .. | 2 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 2 | 3.00 |
| *La* | .. | .. | : | 1 | — | 1 | .. | .. | .. | .. | 1 | .. | .. | .. | 3 | 6.67 |
| *Sr* | .. | .. | .. | .. | .. | 1 | .. | .. | 1 | .. | .. | .. | .. | .. | 2 | 6.50 |
| *Ba* | .. | .. | .. | .. | .. | .. | .. | .. | 1 | .. | .. | .. | .. | .. | 1 | 8.00 |
| *Mg* | .. | .. | .. | .. | .. | .. | .. | .. | .. | 1 | .. | .. | .. | .. | 1 | 10.00 |
| *Zn* | .. | .. | .. | 1 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 1 | 3.00 |
| *Ce* | .. | .. | .. | 1 | .. | 1 | .. | .. | .. | .. | .. | .. | .. | .. | 2 | 4.00 |
| — | .. | 3 | 21 | 17 | 4 | .. | .. | .. | .. | .. | .. | .. | .. | .. | 46 | 2.44 |
| Total | 4 | 34 | 87 | 91 | 62 | 41 | 20 | 3 | 10 | 3 | 1 | 4 | 2 | 1 | 363 | |

Table IV gives all the lines in Rowland's tables having an intensity of 2 and greater, arranged according to scale of intensities (1–1000).

There are 874 lines having an intensity of 2 and over (41 of the 915 being identified with more than one element). 657 of these lines have an intensity less than 4.

TABLE IV.

LINES IN ROWLAND'S MAP BETWEEN H AND F. SCALE 1–1000.

Intensities 2 and greater.

| Element | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 10 | 12 | 15 | 20 | 30 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Fe* | 135 | 108 | 75 | 40 | 15 | 2 | 7 | 3 | 0 | 4 | 1 | 1 | 391 |
| *Ti* | 42 | 24 | 15 | 3 | 4 | .. | .. | .. | .. | .. | .. | .. | 88 |
| *Cr* | 22 | 19 | 6 | 5 | 1 | 1 | 1 | .. | .. | .. | .. | .. | 55 |
| *Mn* | 24 | 14 | 8 | 6 | 3 | 1 | .. | .. | .. | .. | .. | .. | 56 |
| *V* | 12 | 7 | 2 | — | 1 | .. | .. | .. | .. | .. | .. | .. | 22 |
| *Zr* | 9 | 2 | — | 2 | .. | .. | .. | .. | .. | .. | .. | .. | 13 |
| *Ni* | 18 | 10 | 3 | — | 1 | .. | .. | .. | .. | .. | .. | .. | 32 |
| *Ca* | 4 | 5 | 9 | 2 | .. | .. | .. | .. | .. | .. | 1 | .. | 21 |
| *Sc* | 1 | 5 | 1 | 1 | .. | .. | .. | .. | .. | .. | .. | .. | 8 |
| *Co* | 9 | 4 | 5 | 2 | 1 | .. | .. | .. | .. | .. | .. | .. | 21 |
| *Y* | — | 2 | 1 | .. | .. | .. | .. | .. | .. | .. | .. | .. | 3 |
| *La* | 4 | 1 | 1 | 1 | .. | .. | .. | | 1 | .. | .. | .. | 8 |
| *Sr* | — | 1 | — | 1 | — | — | 1 | .. | .. | .. | . | .. | 3 |
| *Ba* | 1 | .. | .. | .. | .. | .. | 1 | .. | .. | .. | .. | .. | 2 |
| *Zn* | .. | 2 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 2 |
| *Nd* | 4 | 1 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 5 |
| *Si* | .. | .. | .. | 1 | .. | .. | .. | .. | .. | .. | .. | .. | 1 |
| *C* | 4 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 4 |
| *Mg* | .. | .. | .. | 2 | .. | .. | .. | 1 | .. | .. | .. | .. | 3 |
| *Ag* | .. | 1 | .. | .. | .. | .. | .. | .. | .. | .. | . | .. | 1 |
| *Cd* | .. | 1 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 1 |
| *Ce* | 3 | 2 | — | 1 | .. | .. | .. | .. | .. | .. | .. | .. | 6 |
| — | 120 | 36 | 9 | 1 | 1 | 1 | 1 | .. | .. | .. | .. | .. | 169 |
| Total | 412 | 245 | 135 | 68 | 27 | 5 | 11 | 4 | 1 | 4 | 2 | 1 | 915 |

Although we cannot directly compare the intensities of the bright lines of the flash (scale 0–10) with those of the dark lines given in Rowland's tables (scale 1–1000), we arrive at certain theoretical considerations if we compare the ratios of the average intensities of the different elements, that is, $\frac{\text{Flash intensities}}{\text{Solar intensities}}$, and also the ratio of the number of lines of each element identified to the whole number of solar lines for that metal. Forming these ratios and arranging them, we are at once struck with the systematic variations not only in the ratio of intensities, but also in the percentage of lines identified.

The meaning of these systematic differences will be understood if we consider these ratios in combination with the atomic

weights of the various elements, as is done in Table V, where also are put down the number of lines of the flash due to each metal.

TABLE V.

| Element | Atomic Weight | Number of Lines Identified | $\frac{\text{Intensity Flash}}{\text{Intensity Solar Lines}}$ | $\frac{\text{Number of Lines Identified}}{\text{Total Number of Lines}}$ |
|---|---|---|---|---|
| GROUP I. LINES STRONG IN FLASH AND IN SOLAR SPECTRUM. | | | | |
| *Na* | 23.0 | — | — | — |
| *Mg* | 24.3 | 1 | 0.10 | 1.00 |
| *Al* | 27.1 | — | — | — |
| *Ca* | 40.0 | 8 | 0.34 | 0.38 |
| GROUP II. LINES STRONG IN FLASH, WEAK IN SOLAR SPECTRUM. | | | | |
| *Sc* | 44.1 | 6 | 0.81 | 0.75 |
| *Ti* | 48.1 | 62 | 0.68 | 0.70 |
| *V* | 51.2 | 15 | 0.68 | 0.67 |
| *Cr* | 52.1 | 38 | 0.55 | 0.69 |
| *Mn* | 55.1 | 27 | 0.24 | 0.48 |
| *Sr* | 87.6 | 2 | 1.08 | 0.67 |
| *Y* | 88.7 | 2 | 0.50 | 0.67 |
| *Zr* | 90.6 | 9 | 0.46 | 0.70 |
| GROUP III. LINES WEAK IN FLASH, STRONG IN SOLAR SPECTRUM. | | | | |
| *Fe* | 56.0 | 125 | 0.20 | 0.32 |
| *Ni* | 58.7 | 9 | 0.36 | 0.28 |
| *Co* | 59.0 | 6 | 0.19 | 0.29 |

Looking at the numbers in the last two columns, we see that the lines naturally fall into three groups as given in the above table.

To these may also be added the following lines:

*La*, atomic weight 138.5, 3 lines at $\lambda$ 4123.384, $\lambda$ 4217.720 and $\lambda$ 4613.544.
*Ba*, atomic weight 137, 1 line, at $\lambda$ 4554.211; and the following lines possibly identified:
*Si*, atomic weight 12, 1 line, at $\lambda$ 3905.660.
*Zn*, atomic weight 65, 1 line, at $\lambda$ 4810.724.
*Ce*, atomic weight, 92, 2 lines at $\lambda$ 4003.912 and $\lambda$ 4107.649.

In Group I would also fall *Al*, if we consider the relative intensities of the two lines $\lambda$ 3944.160 and $\lambda$ 3971.674; and undoubtedly *Na*, if our plate took in the D lines.

The grouping of these lines is exactly that adopted by Evershed from his investigations of the Indian eclipse, except that I have put *Zr* with *Sr* and *V* in Group II. *Mn* seems to represent the transition from Group II to Group III.

Sir William and Lady Huggins[1] called attention to the great heights to which *Ca* extends in the Sun's atmosphere, and it is on account of this great extent that H and K are such prominent lines not only in the absorption spectrum, but in the emission spectrum. As Evershed[2] has pointed out, the remarkable variations of the relative intensities in the flash and Fraunhofer spectra are undoubtedly due to the heights to which the vapors of the different metals ascend in the chromosphere. We would naturally expect that these heights vary according to the atomic weights of the metals, those of least atomic weights ascending to the greatest distances; and generally speaking this no doubt is true. But if we have two gases in the Sun's atmosphere, one a gas with an intrinsic brightness 1 and a layer 100 miles in thickness, it would give a photographic line in the flash spectrum just as bright as the other gas of intrinsic brightness 100 and only 1 mile thick, if the Sun and Moon were relatively at rest during the period of the "flash;" but considering the gradual advance of the Moon in covering successive layers of the Sun's atmosphere, we see that in the emission spectrum the photographic brightness of the fainter gas would be many times that of the brighter. The absorption caused by a gas depends on the total number of molecules the solar ray comes in contact with, and will be very nearly equal in the two cases.

In view of these considerations, it would therefore seem that the gases of the metals of Group II extend very high, that they are nowhere very much condensed, and that practically all the gas contributes to the formation of the emission line; and hence

[1] SIR WILLIAM and LADY HUGGINS, "The relative behavior of the H and K lines of the spectrum of calcium," ASTROPHYSICAL JOURNAL, **6**, 77, 1897.

[2] EVERSHED, "Wave-length determinations and general results obtained from a detailed examination of spectra photographed at the solar eclipse of January 22, 1898." *Phil. Trans. Royal Society*, A, **197**, 381–413. 1901.

the flash lines are to be regarded as true reversals of the corresponding solar lines.

The vapors of Groups I and III are somewhat condensed near the Sun's surface (those of Group I, particularly *Ca*, reach far greater heights than those of Group III), but as it is the upper portions that contribute most to the formation of the emission lines, owing to the progressive motion of the Moon, the flash lines are to be regarded as only partial reversals of the Fraunhofer lines, the solar intensities being greater than the flash intensities.

### UNKNOWN LINES.

Taking account of lines in the flash identified with groups in the solar spectrum, about half the lines in Table IV have corresponding lines in the flash. From the above considerations we see that it is highly improbable that lines of intensity 2 in the solar spectrum, and belonging to Groups I and III, will have flash lines corresponding to them of sufficient brightness to show in this flash. In fact, by reference to Tables III and IV, we see that although there are 135 *Fe* lines of intensity 2, only 11 of these are found in the flash, and indeed, great numbers of the feebler solar lines are lacking in the flash. But if, on the other hand, we compare the stronger lines, we see that every strong line of the solar spectrum is almost without exception found in the flash spectrum.

And so, remembering the meaning of the differences of intensities, we see no reason for giving up our faith in the existence of the "reversing layer."

We may obtain an approximate estimate of the depths of the layers producing the bright arcs by measuring the angular extent of the arcs. Accordingly the lengths of some of the more conspicuous bright lines have been measured, and thence were deduced the elevations of the luminous layers producing the bright lines of the flash spectrum. In calculating, the semi-diameter of the Sun was taken as 948$''$.4, and the Moon's augmented semi-diameter 1013$''$.8. For the purposes of comparison,

the same arcs were taken that Frost has measured. The depths of the luminous layers of the various metallic vapors come out as follows:

TABLE VI.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Spectrum line.... | *H* 3970 | *He* 4026 | *Sr* 4078 | *H*$\delta$ 4102 | *Sr* 4215 | *Ca* 4226 | *Sc ?* 4247 | *Fe pair* 4250 | *Cr* 4254 |
| Approximate height of layer. | 8″ | 4″ | 4″ | 7″ | 4″ | 2.″5 | 2.″5 | <½″ | 2.″5 |
| Spectrum line.... | *Cr* 4274 | *Sc* 4321 | *H*$\gamma$ 4340 | *Ti* 4395 | *He* 4471 | *Ti* 4501 | *Ti* 4549 | *Ba* 4554 | *H*$\beta$ 4861 |
| Approximate height of layer. | 2″ | 2″ | 8″ | 2″ | 7″ | 2″ | 2″ | 2.″5 | 8″ |

Comparing these heights with the intensities given in my scale (0—10), it is seen that roughly speaking the heights in seconds of arc is 0.8 of the value of the intensity for Group II, and 0.4 for Groups I and III. The arcs of the great majority of the lines are no longer than the *Fe* pair at $\lambda$ 4250, which correspond to an extent of ½″.

As a result we may safely infer that the average depth of the "reversing layer" is about 1″, although from the above considerations we see that the heights to which the gases extend and their condensations are different for the different elements.

These results differ materially from those of Sir Norman Lockyer given in his *Recent and Coming Eclipses*, p. 111. The numbers of lines photographed at the eclipses of 1893 and 1896 are there given by him as 164 and 464, respectively. As there are 5694 lines in the same region in Rowland's map, he decides that only 3 and 8 per cent. respectively of the solar lines are reversed in the flash at these two eclipses. But as Professor Frost has pointed out,[1] the instruments employed were capable of photographing only a small fraction of the 5694 lines of Rowland's map.

Sir Norman lays great stress on the fact that great numbers of "enhanced" lines, or lines stronger in the spark than in the

[1] ASTROPHYSICAL JOURNAL, 12, 346, 1900.

arc spectrum, are found in the spectrum of the chromosphere. In order to investigate this idea, close comparisons were made between the above flash lines and the latest list of "enhanced" lines given by Lockyer in *Proc. R. S.*, **65**, 452, 1900.

Taking up first titanium, as the "enhanced" lines for this metal are most numerous, it is found that he has given fifty-three lines between λ 3900 and λ 4590. This region is all included in the photographs of the flash. Thirty out of the fifty-three "enhanced" lines certainly appear as bright lines in the flash, eleven do not appear, the other twelve are doubtful from their proximity to strong flash lines, or from their being situated in a group in the flash. Thus 56 per cent. of the "enhanced" lines of *Ti* are found as chromosphere lines; and this would seem to strongly support Lockyer's views. But, on the other hand, every one of these thirty lines, without exception, appears as a strong line in the solar spectrum; and the coincidence between "enhanced" and flash lines does not prove anything definite, for where there are strong Fraunhofer lines we expect strong reversals in the flash. A real test would be the case where there is a strong "enhanced" line, but no strong solar line corresponding to it. Such a line occurs in titanium at λ 4308.60, where the intensity in the spark is 7, and on the same scale in the arc 1–2. There is a line in Rowland's tables at λ 4308.601 with an intensity of 00, but there is certainly no exceptionally strong flash line which we would be led to expect if Lockyer's idea is correct. The appearance of this line may be contrasted with that at λ 4563.94. Both have the same intensity in the spark (*loc. cit.*), but to λ 4563.94 corresponds a strong line of intensity 4 on Rowland's scale, and a strong reversal in the flash of intensity 5 on my scale.

The conclusions from the "enhanced" lines of iron agree with those for titanium, *i. e.*, there are a great number of strong lines in the flash spectrum corresponding to the "enhanced" lines, but they also correspond to strong Fraunhofer lines.

A severe test of the idea that "enhanced" lines are found with great frequency in the spectrum of the chromosphere will

be given by the metal vanadium. Lockyer gives twenty-five lines between λ 3885.05 and λ4243.10, the majority of which are decidedly stronger in the spark than in the arc. Only four of these lines are with certainty found in the flash, corresponding to Lockyer's lines at λ 4005.85, λ 4035.80, λ 4225.41, and λ 4243.10. The first two of these have corresponding strong solar lines; the second two have not; none of the four lines, however, are identified by Rowland as due to vanadium. Three out of nineteen "enhanced" lines of manganese are found in the flash.

From these comparisons it would seem that there is no close connection between "enhanced" lines and the bright lines of the chromosphere seen in the flash.

Lockyer's latest measures may perhaps serve to find the chemical origin of some of the lines unassigned by Rowland. The following lines, unidentified in Table I, may therefore be assigned to different metals. The numbers in (1) are the intensities given in Rowland's tables.

To *Fe* can be assigned the lines at: λ 4179.025 (3); 4296.735 (3); 4385.548 (2); 4489.351 (2); 4491.570 (2); 4508.455, *Fe?*– (4); 4515.508 (3); 4520.397, *Fe?*– (3); 4522.802 (3); 4576.512 (2).

To *Ti*, the lines at λ 4161.682 (4); 4173.710 (3); 4184.472 (2); 4590.126 (3).

To *Cr*, λ 4588.381 (3); λ 4634.254 (2); and to *V* the line λ4005.856.

Columbia University,
New York City,
January 1902.

# THE EFFECT OF SODIUM ON THE HYDROCARBON BANDS IN THE SPECTRUM OF THE BUNSEN FLAME.

By Percival Lewis.

Scheiner, in his *Astronomical Spectroscopy* (Frost's translation, p. 217), makes the following statement:

> If sodium vapor be introduced into a Bunsen burner which is giving a fine hydrocarbon spectrum, the latter will not be in the least diminished, but will appear as intense as before, the sodium line simply appearing in addition.

In discussing the causes of the relative changes in intensity of the D lines and the hydrocarbon spectrum of Comet 1882 I, as it approached the Sun, he cites the above fact as evidence of the electrical origin of the luminosity of this and other comets.

It seemed worth while to the writer to put this statement to an accurate photometric test, as it was probably based merely on eye estimation. The first experiment was made by fitting a thin asbestos cylinder in the tube of a Bunsen burner, and measuring the intensity of the green hydrocarbon band before and after the asbestos was moistened with a salt solution. The measurements were made with a Glan spectrophotometer, an incandescent lamp being used as a standard of comparison. The first results seemed to confirm Scheiner's opinion, but it seemed very possible that this was due to the fact that the sodium vapor ascended on the outside of the green cone and did not mix with the radiating gas within the cone. On tipping the burner until the tube was nearly horizontal, so that the sodium vapor must ascend through the cone, a very noticeable effect was perceived, manifesting itself chiefly in a great strengthening of the continuous background which always accompanies the sodium spectrum. The positions occupied by the carbon bands underwent no change noticeable to the eye,

but in properly estimating their real intensity deduction must be made of the intensity of the continuous background, determined as nearly as possibly by taking the average of the intensities on both sides of the band.

Below are several series of measurements, taken at different times. The intensities given are merely relative, corresponding parts of the standard source being taken as 100.

| Experiment | + or − Sodium | Apparent I | Background | Real I |
|---|---|---|---|---|
| 1 | − | 81 | 8 | 73 |
| | + | 81 | 18 | 63 |
| 2 | − | 81 | 9 | 72 |
| | + | 76 | 34 | 42 |
| 3 | − | 71 | 9 | 62 |
| | + | 56 | 19 | 37 |
| 4 | − | 45 | 7 | 38 |
| | + | 38 | 16 | 22 |
| | − | 36 | 10 | 26 |
| | + | 28 | 14 | 14 |

The fourth set of experiments was made with a burner of the fish-tail type, placed in a vertical position, the edges being moistened with salt solution. In this case, on account of the thinness of the flame, there was an opportunity for the sodium vapor to mix with the gas.

The diminution in the intensity of the green band is very evident, but somewhat irregular, as one might expect from the impossibility of gauging the amount of sodium vaporized. A quantity of sodium merely sufficient to color the flame uniformly will produce no measurable change; the flame must be almost saturated.

Measurements were not made on the other bands, on account of their feeble intensity and the resulting difficulty of measurement.

On account of the relative weakness of the carbon spectrum, the comparison source was also made weak, hence any accurate measurement of the far greater intensity of the D lines was subject to great error; nevertheless one series of such rough estimations was made, with the following result:

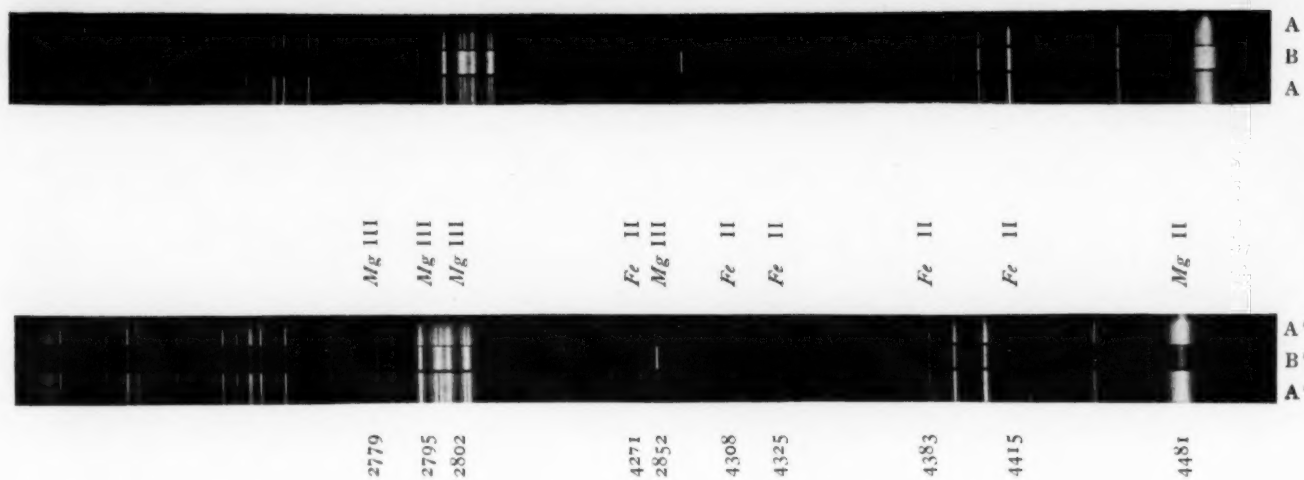
| D Lines | Apparent I green band | Background | Real I green band |
|---|---|---|---|
| 20 | 80 | 8 | 72 |
| 140 | 80 | 10 | 70 |
| 600 | 75 | 10 | 64 |
| 1200 | 38 | 12 | 26 |

In this experiment the background was relatively weak and the measurements of it are subject to error.

These facts may not lessen the probability of the electric origin of cometary radiation, but they indicate that there is no apparent difference between the effects produced on the hydrocarbon spectrum by sodium vapor in the arc or vacuum tube and that in the flame, so far as relative intensities are concerned.

UNIVERSITY OF CALIFORNIA,
January 30, 1902.

PLATE V.




DOPPLER EFFECT AND REVERSAL IN SPARK SPECTRA.

Photographed by JOHN FRED MOHLER.

# THE DOPPLER EFFECT AND REVERSAL IN SPARK SPECTRA.

By John Fred Mohler.

Some time ago I measured the pressure in the electric spark,[1] under certain conditions, using the shift of the lines in the spectra produced as an index. Various causes for this pressure have been advanced, one by Eduard Haschek, who[2] attributes this pressure to the fact that the particles driven off from the electrodes have a very high velocity, and this velocity stopped by collisions with other particles produces pressure. Schuster[3] has given a value to this velocity, having measured it in the spectrum of a spark photographed with a moving film. His values for the zinc lines are from 2,000 to 900 meters per second. Since this work was begun Dr. Schenck[4] has shown that the velocity for some magnesium lines is greater than the values Schuster obtained for zinc. Dr. Schenck used a revolving mirror, and his results show a maximum velocity of 2.5 kilometers per second for the magnesium line at $\lambda$ 4481.

This work was begun more than a year ago. My plan was to get the spectra of certain metals when the particles were driven away from the slit of the spectroscope, and then get the same lines when the particles were driven toward the slit. The electrodes were of different metals placed in a line perpendicular to the plane of the slit; and after the spectrum was obtained in this position, they were turned 180°, reversing the direction of the particles projected from the electrodes, and this spectrum was photographed alongside of the other. Displacement due to motion in line of sight would thus be doubled and the displacement due to this cause would be in the opposite directions for the lines of the different electrodes.

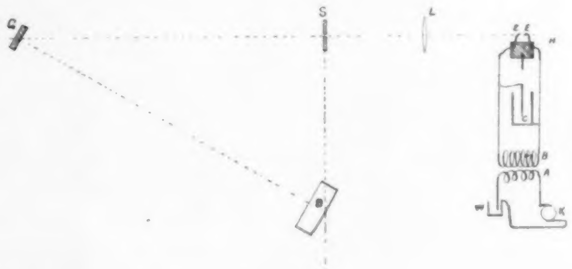
[1] Astrophysical Journal, 10, 202, 1899.

[2] *Ibid.*, 14, 181, 1901.

[3] *Nature*, 57, 17, 1897.

[4] Astrophysical Journal, 14, 116, 1901.

The diagram of the apparatus will make clear the method. *A* is the primary of an induction coil supplied with current from a 110-volt generator *K*, through a Wehnelt break *W*. The coil thus excited would give a shower of sparks 18 cm long. The secondary *B* was connected to the electrodes *e e* and Leyden jar *C* of 0.0025 microfarads capacity (22.5 meters). Thus arranged, the spark gap was not over 9 mm long, and in most cases the gap was 6 or 7 mm. For part of the work a mercury break was used, but as the Wehnelt break would give good photographs with 5 to 10 minutes exposure and the mercury



break required 30 to 60 minutes, the former was used for most of the work.

The wires used for electrodes were small and arranged as in figure. The block *H* of hard rubber furnished good insulation and permitted the electrodes to be quickly revolved 180°. By slightly inclining the electrodes the wire itself did not obscure the light of the spark. The discharge was oscillatory with this arrangement, and very noisy. *G* is an excellent 4-inch grating of ten feet radius, ruled 14,400 lines to the inch. The work was done in the second, third, and fourth order of spectra. The grating is mounted in a basement on solid masonry pillars and the temperature was kept very constant. The induction coil, break, and resistance for controlling the current, were in the room above the one occupied by the grating. The spectra were photographed in the usual way.

RESULTS.

The most noticeable results were not the displacement of the lines due to the Doppler effect, but, in the case of some of the magnesium lines, the very marked difference in the *character* of the lines. When the spark from the magnesium was going *away* from the slit, the lines at $\lambda\lambda$ 2795, 2802, and 2852 would be very strongly reversed, similar to the appearance of the line at $\lambda$ 2852 in the arc, and when the spark was coming toward the slit from the magnesium electrode the lines would be without reversal. This was not due to difference in time of exposure or intensity of the lines, as the photographs themselves plainly show. In much less degree this effect is noticed in the line at $\lambda$ 2779. When the spark passes in a direction at right angles to the axis of the spectroscope the reversal is still noticed, but is not nearly so marked. Reversing the direction of the current through the primary produced no difference in the effect, for, as stated above, the discharge from the Leyden jar was oscillatory. Motion in the line of sight produces a very small displacement, so small in fact that it is near the limit of measurement with the instruments at my disposal. The displacement of the lines was measured with an eyepiece micrometer made by Bausch & Lomb Optical Co., in connection with a low power objective.

The lines which gave Dr. Schenck his large value of 2.5 kilometers per second as the maximum velocity are far too wide and shaded to be measured accurately. From this maximum the velocity fell off rapidly until a little short of the middle of the spark it was probably only one-tenth as great. If the spark is observed exactly end on, the average of this variable velocity would be measured, but by inclining the spark just a little, light from near the electrode only would illuminate the slit. However, the sparks spread out somewhat in a sheaf so that it was impossible to entirely isolate the one point in the spark near the electrode, and on all plates some of the lines from the other electrode would appear, showing that the light on the slit was from different parts of the spark. What I get, then, is probably

the average velocity of the particles in the spark. The measurements of the plates show that the aluminium lines at λλ 3961 and 3944 give an average measured displacement of 0.01 tenth-meters. As this is double the actual displacement from normal position the velocity would be 0.37 km per second. The results for the iron lines at λλ 4063, 4071, 4260, 4271, 4308, 4325, 4383, and 4415 give slightly smaller velocity. The magnesium lines at λλ 2776, 2778, 2779, and 2781 gave about the same result as the iron lines, and the cadmium lines at λλ 4078 and 4800 showed a slightly larger velocity.

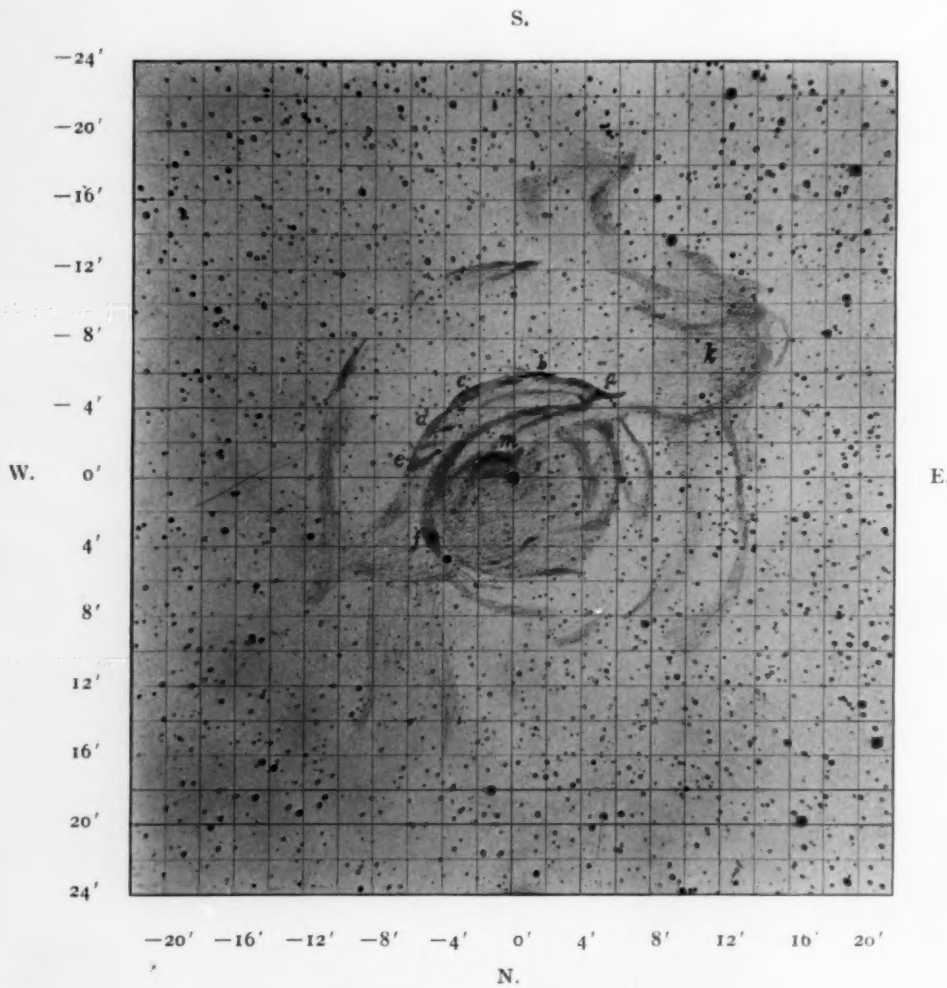
The work is still in progress and I hope to add to the results given above.

## EXPLANATION OF THE PLATE.

The spectra *A* were taken when the magnesium was sparking away from the slit and the iron was sparking toward the slit. The spectra *B* were taken with positions reversed. In the second case the *B* spectrum was exposed a shorter time to show that the lack of reversal was not due to long exposure. The Roman numerals refer to the order of spectrum.

Dickinson College,
January 15, 1902.

PLATE VI.




NEBULOSITY ABOUT *NOVA PERSEI*, SEPTEMBER 20, 1901.

Photographed with the Two-Foot Reflector, Yerkes Observatory.

Fxposure $3^{h}$ $50^{m}$.

# NEBULOSITY ABOUT *NOVA PERSEI.*

## RECENT PHOTOGRAPHS.

By G. W. Ritchey.

Up to the present time thirteen negatives of the nebula about *Nova Persei* have been obtained with the two-foot reflector, as follows:

| Date. | Exposure. | | Remarks. |
|---|---|---|---|
| September 20 | $3^h$ | $50^m$ | Seeing fine. |
| November 9 | 1 | 30 | Seeing good. Exposure stopped by clouds. |
| November 13 | 7 | 0 | Seeing good. |
| November 20 | 3 | 0 | Seeing good. Exposure stopped by clouds. |
| November 30 | 3 | 0 | Seeing poor. Exposure stopped by clouds. |
| December 4 | 1 | 45 | Seeing poor. Exposure stopped by clouds. |
| December 14 | 4 | 30 | Seeing poor. Night extremely cold and transparent. |
| January 2 and 3 | 10 | 0 | Seeing poor. |
| January 7 and 9 | 4 | 30 | Seeing fine. |
| February 8 | 2 | 40 | Seeing good. |
| February 10 | 4 | 30 | Seeing poor. |
| February 25 | 1 | 30 | Seeing good. Exposure stopped by clouds. |
| March 4 and 5 | 3 | 15 | Seeing good. Exposure stopped by clouds. |

On account of the wide-spread interest in this nebula and in the theories which have been suggested concerning it, it has been thought best to publish now the diagrams which I have prepared from the best five of the negatives, together with a very brief description. These diagrams show the continued changes which have taken place in the principal ring of nebulosity, and include also the more conspicuous of the faint nebulosities outside of the principal ring. These outer nebulosities are in most cases so faint that they would not be recognized with certainty as real nebulosity, in the examination of a single negative; by studying the entire series, however, it is possible to trace these excessively faint outlying masses with considerable certainty, and to follow the apparent changes of position in some of them.

The faint details shown in the diagrams are in nearly every case present in more than one of the negatives. The positions of

these outer nebulosities, and the changes which have occurred in them, are very suggestive in connection with the theories which have been advanced regarding the apparent expansion of the nebula.

Measures and a discussion of the entire series of negatives, including those of March and April (after which time this object will be inaccessible for photographing for several months), will be published soon.

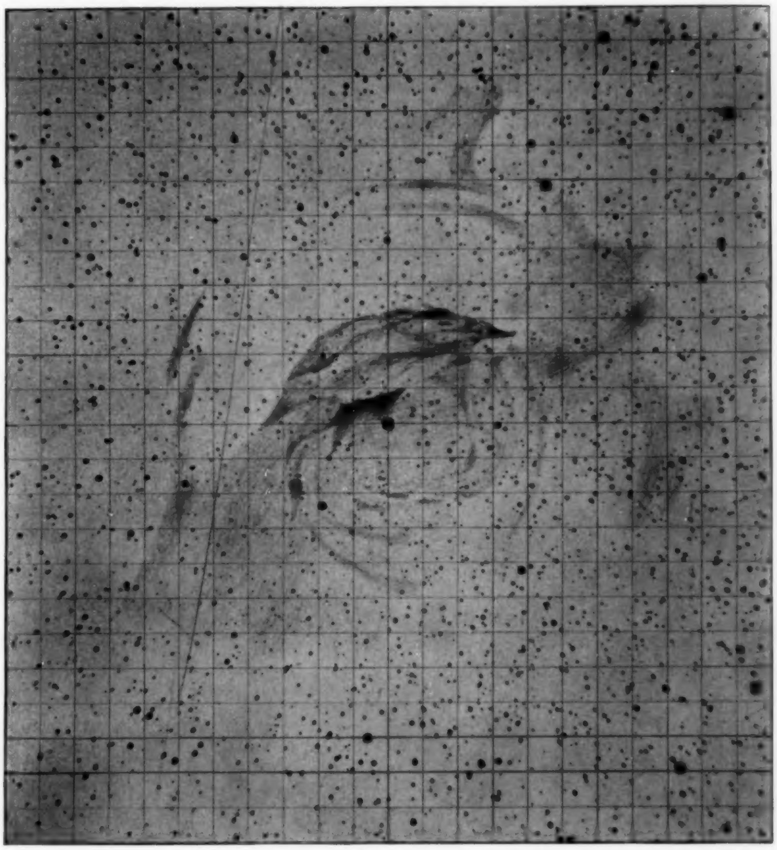
The principal ring of nebulosity, shown in my earlier drawings,[1] has continued to fade rapidly. Only the condensations *a* and *b* remain conspicuous on the later negatives. The parts of the principal ring to the southwest of the *Nova* have become so faint that they can be seen only with the greatest difficulty on the negatives obtained in February and March. The strong condensation *m*, close to the *Nova*, has apparently not changed in brightness since November 9. Its form is changing slowly, however; it is expanding toward the south. This part of the nebula is so distinct that there can be no doubt of this change of form, though it is small.

On the negative of September 20 the outer nebulosities appear as segments of a fairly well-defined ring about 25′ in diameter (Plate VI). On account of favorable atmospheric conditions this negative is very sharp and brilliant, and finer details are shown than in any of the other negatives except that of January 7 and 9. In all of the later negatives parts of this outer ring are shown to be receding from the *Nova;* this is certainly true of those parts to the south and west, and also of the remarkable group of nebulous wisps to the north, which are shown only on the photographs taken after January 1.

The large, diffused mass of nebulosity, *k*, to the southeast of the principal ring, is well shown on all of the negatives which received more than two hours' exposure. No very well-defined details can be seen in it, and no change of form can be detected with certainty. It is a suggestive fact that this large mass lies in the direction from the *Nova* in which the strong condensation

[1] ASTROPHYSICAL JOURNAL, October and November 1901.

PLATE VII.

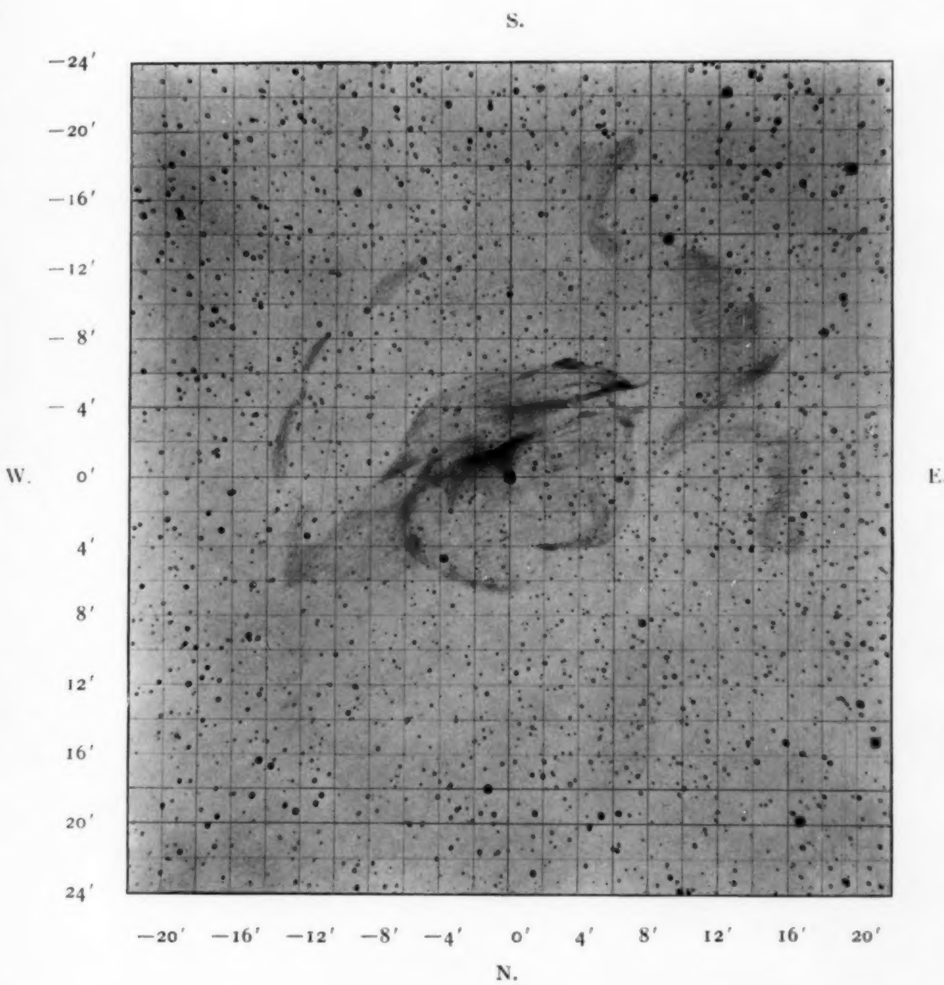



NEBULOSITY ABOUT *NOVA PERSEI.* NOVEMBER 13, 1901.

Photographed with the Two-Foot Reflector, Yerkes Observatory.

Exposure $7^h$.

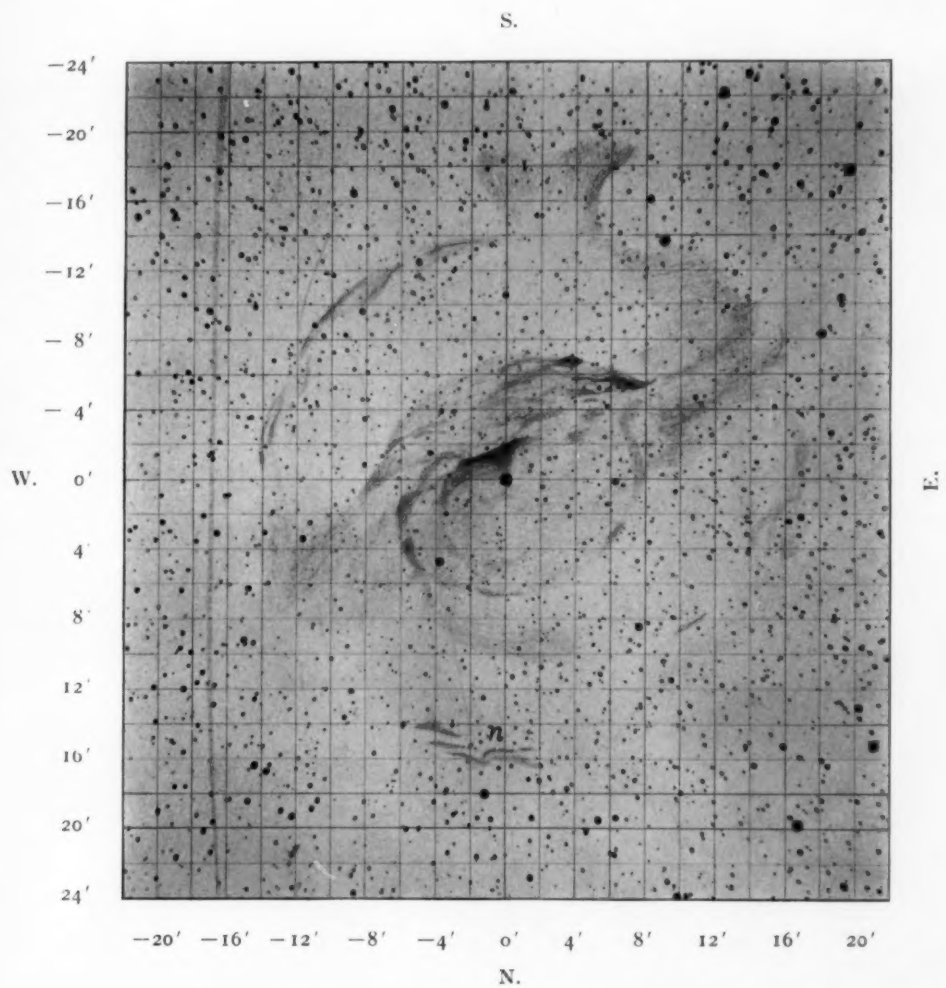
PLATE VIII.




NEBULOSITY ABOUT *NOVA PERSEI*, DECEMBER 14, 1901.

Photographed with the Two-Foot Reflector, Yerkes Observatory.
Exposure $4^h$ $30^m$.

PLATE IX.

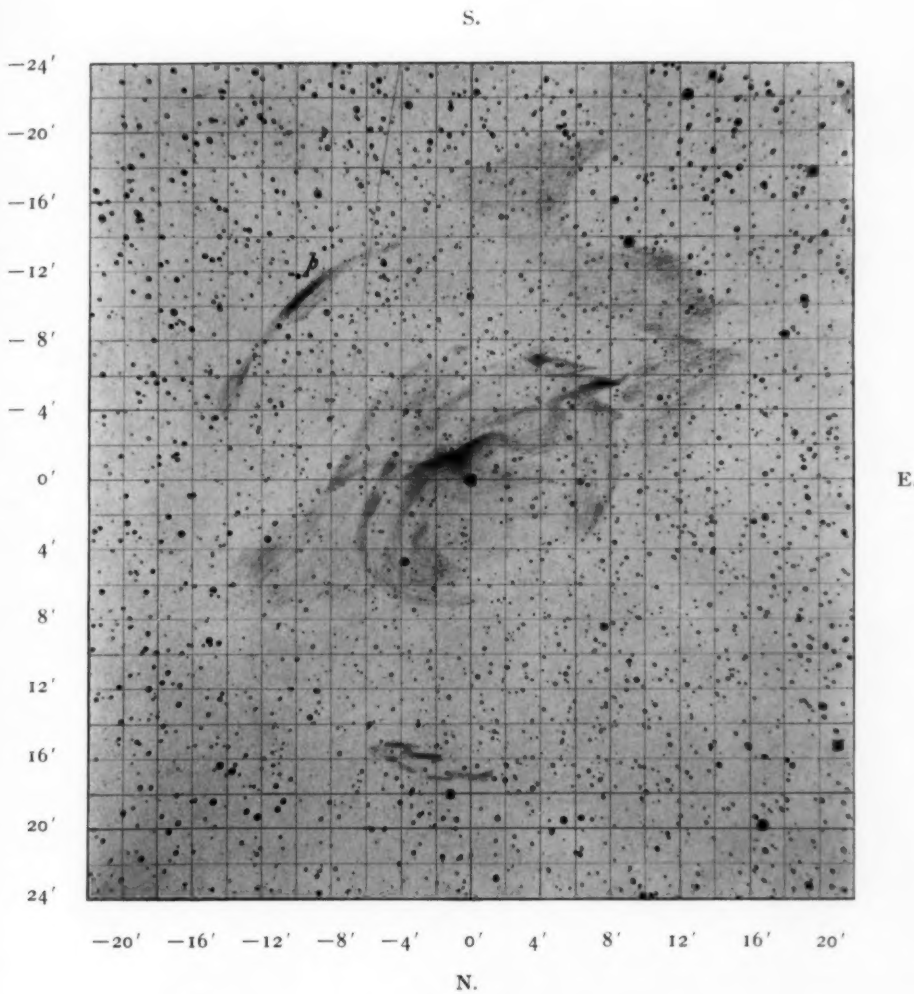



NEBULOSITY ABOUT *NOVA PERSEI.* JANUARY 7 AND 9, 1902.

Photographed with the Two-Foot Reflector, Yerkes Observatory.

Exposure $4^h$ $30^m$.

PLATE X.




NEBULOSITY ABOUT *NOVA PERSEI*, FEBRUARY 8, 1902.

Photographed with the Two-Foot Reflector, Yerkes Observatory.

Exposure $2^h$ $40^m$.

*a* of the principal ring is apparently moving. On one negative, that of January 7 and 9, which is one of the sharpest of the series, a faint straight wisp in this mass extends in what is apparently the line of motion of the condensation *a*. (See Plate IX.)

The remarkable group of nebulous wisps, *n*, to the north of the *Nova*, at a distance of about 16′, has already been mentioned. These wisps are invisible on the negatives obtained before January 1, and are strongly shown on the negatives of January 7–9 and February 8, with a well-marked change of position between these dates, as shown in Plates IX and X.

It will be noticed that on the negative of February 8 there is a very strong wisp in the part of the outer ring to the southwest of the *Nova*, at a distance of about 14′ from the latter (*p*, Plate X). On this negative, and on the three which have been secured since February 8, this wisp is the strongest part of the entire nebula, excepting only the condensations *m* and *a*. This wisp is so strong and distinct on the four negatives just mentioned that there cannot be the slightest doubt of its rapid change of position. This apparent movement is outward and nearly radial.

In speaking of motion and of change of form in the above paragraphs I have in all cases meant *apparent* change only, and have not intended to express the opinion that there is actual motion of matter. The rapid fading of parts of the principal ring, and the sudden brightening and rapid outward movement of parts of the outer ring, notably those to the north and to the southwest of the *Nova*, are phenomena which strongly support the theory suggested by Kapteyn and others, that the apparent motion is due to changes of illumination of a stationary nebula.

On account of the illness of the writer, the exposures in the telescope of all of the negatives obtained since December 1 have been made by Mr. Francis G. Pease.

YERKES OBSERVATORY,
March 1902.

# NOTE ON THE SPARK SPECTRUM OF IRON IN LIQUIDS AND IN AIR AT HIGH PRESSURES.

By George E. Hale.

In a study of the spark spectrum of iron and other metals in liquids, undertaken in connection with investigations of the spectra of temporary and red stars, I have encountered certain phenomena of which some preliminary notice seems desirable. It is to be understood that most of the results here presented are derived from a general reconnaissance, and that only a prolonged quantitative investigation, which is now in progress, can be expected to yield data suitable for study in connection with related astronomical and physical phenomena.

The transformer employed is wound to give either 15,000 or 30,000 volts when supplied with an alternating current of 110 volts, but in the present work a resistance of about four ohms was inserted in the circuit of the 3 K. W. alternator (133 cycles), reducing the voltage of the primary current to about 25 and the current to about 20 amperes. Under these conditions, with a condenser of 0.0015 microfarads capacity, electrodes (in water) of Bessemer steel 1 mm in diameter, with flat ends, separated from each other by a distance of about a millimeter; and auxiliary electrodes (in air, connected in series with the electrodes in water and the terminals of the transformer) of Bessemer steel, 1 mm in diameter, with flat ends, separated from each other by a distance of about 12 millimeters: the spark in water gives a spectrum of the type shown in Plate XI, Fig. 2. By changing the diameter or separation of the electrodes, the capacity of the condenser, etc., or by replacing the water by some other liquid, as will be explained below, spectra like those shown in Figs. 3 and 4 can be obtained. With the above transformer this degree of absorption has been surpassed in pure water, but if the spark is taken in a solution of 1 part of common salt in 800 parts of distilled water the effect is intensified,

PLATE XI.


**Photographs of the Spark Spectrum of Iron in Air (1), in Water (2, 3, 4), and in Sodium Chloride Solutions (5, 6).**

**Made with a One-Prism Spectrograph by George E. Hale.**

and the spectrum becomes like that shown in Fig. 5. A 4 per cent. solution of common salt gives the absorption phenomena shown in Fig. 6, while an 8 per cent. solution further increases the intensity of the dark lines. A 9.5 per cent. solution of $BaCl_2$ produces the strongest absorption effect hitherto observed. The accompanying illustrations give some of the more marked stages in the process of reversal, but many intermediate steps have been recorded.

Within certain limits, it may be said that the reversals tend to increase in number and intensity (1) with the length of the auxiliary (air) spark; (2) with the diameter of the electrodes at either spark gap; (3) with the capacity of the condenser; (4) with the pressure of the water (other things being equal, spectra photographed with the spark 2.5 cm and 615 cm below the surface of the water respectively show a very distinct difference); (5) in solutions of sodium chloride and other salts, with the strength of the solution. On the other hand, the reversals tend to decrease in a very striking way as the length of the spark in the liquid is increased. Thus with an auxiliary spark gap of 12 mm, a spark in water 0.2 mm long gives a spectrum similar to Fig. 4, while an increase of the length to 1 mm changes the spectrum to the type shown in Fig. 2. In this case the electrodes were of iron wire 2.3 mm in diameter, with flat ends; the auxiliary electrodes of Bessemer steel were of 0.5 mm and 3 mm diameter respectively, with flat ends. It is perhaps well to point out that all of the changes referred to relate to the iron lines of the spark, and not to lines due to substances present in the particular liquid employed.

Other experiments, to be described in detail later, may be briefly referred to here. Spectra containing no dark lines were obtained from the spark which occurs in a Wehnelt interrupter (iron rod in $KOH$ solution; direct current, 110 volts); from a rotating arc with iron poles in water (direct current, 110 volts); from the discharge between iron poles in water of an Apps induction coil wound to give a 30 cm spark (alternating current of 11 amperes through primary); and from the discharge

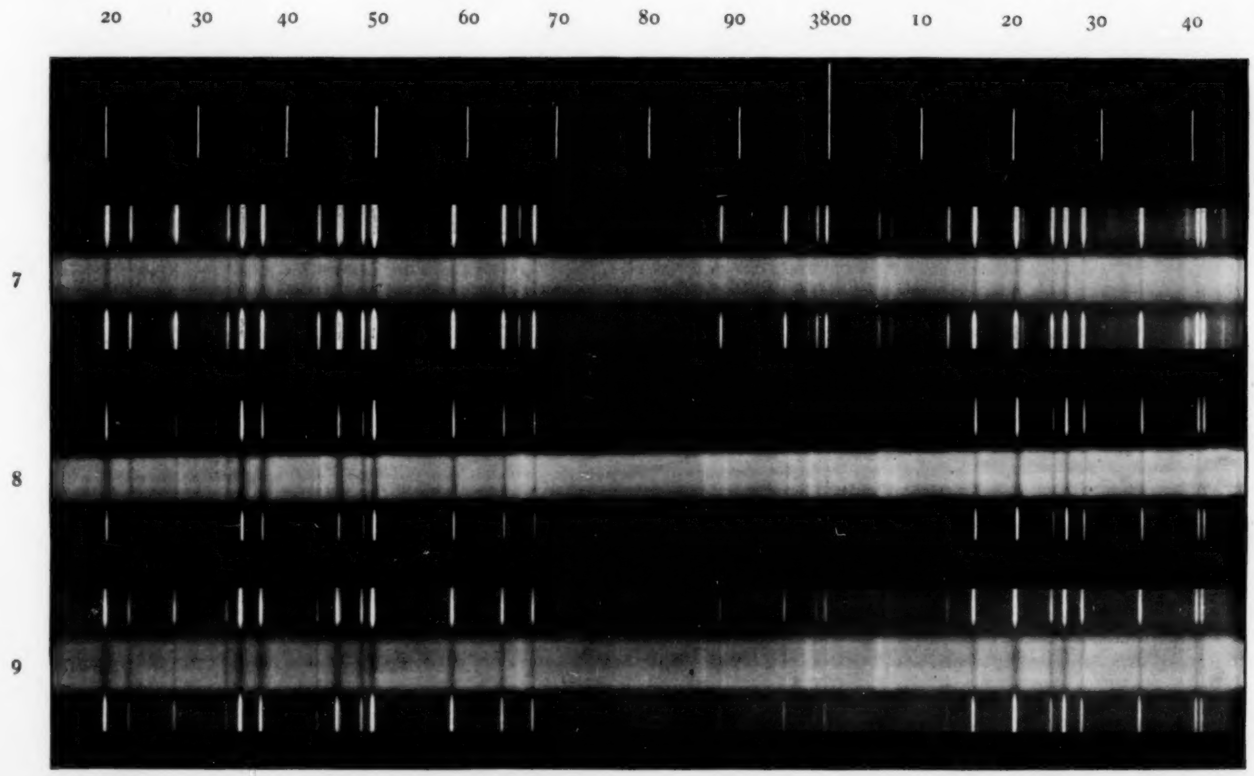
in water of a high frequency coil whose primary was connected with the secondary of the 15,000-volt transformer. All of these spectra, except for certain changes in the relative intensities of the lines, resemble the spectrum of the iron spark in air, and contain no reversals.

The blue region of the spectrum of the transformer spark in air has also been observed at pressures up to twenty atmospheres, with results which harmonize well with those of Humphreys and Mohler, obtained with the arc at lower pressures. The iron lines remain fairly sharp, and are shifted toward the red by an amount which seems from preliminary measurement to be directly proportional to the pressure. The phenomena are thus very different from those observed in water.

In order to study the shifts of the lines of the spark in water the spectrum under various conditions has been photographed with a concave grating spectroscope of 21 ft. focal length. Portions of some of the spectra, in each case accompanied by a comparison spectrum of the iron spark in air, are reproduced in Plate XII. It will be seen that during the transition from the bright line to the dark line conditions represented in Plate XI, the spectra show both bright and dark lines simultaneously. The scale of the photographs is sufficient to render visible the shifts of the lines, which are now under investigation.

In repeating these experiments it will be interesting to follow the changes of the iron triplet $\lambda\lambda$ 3763.95, 3765.69, 3767.34. In the spark in air and in the 110-volt arc or high frequency spark in water, the two outer lines are much more intense than the central line. Kayser and Runge give all these lines the same intensity in their table of the arc spectrum of iron, but the photographic map which accompanies the table shows the central line to be decidedly fainter than the others. Hemsalech's table of spark lines gives the intensities as 8, 7, 8, and shows that self-induction increases the intensities of the two outer lines to 10, but does not affect the central line. With the transformer spark in water it is possible to obtain the lines of equal intensities. The general effect of the water is to strengthen the

# PLATE XII.




PHOTOGRAPHS OF THE SPARK SPECTRUM OF IRON IN WATER.

Made with the 21-foot Concave Grating Spectroscope of the Yerkes Observatory, by George E. Hale.

central line and to weaken the other two. Intermediate effects are shown in Figs. 7 and 8, Plate XII, while Fig. 9 represents fairly strong absorption, which would be further intensified in a salt solution. The scale of the reproductions is sufficient to show the peculiar shifts of the various lines under these conditions. Professor Crew, who has very kindly confirmed some of these results in his own laboratory, informs me that the relative intensities of the lines of the triplet in the arc are not affected by an atmosphere of hydrogen or of oxygen.

Although it appears not improbable that the energy of the discharge is the principal variable concerned, a discussion of the results in the absence of quantitative data would be premature. It does not seem from the experiments so far made that the electrical conductivity of the solution is a dominant factor (*e. g.*, kerosene oil gives an effect closely resembling that obtained with a 4 per cent. *NaCe* solution). Experiments to test the effect of self-induction (with and without iron cores in the coils) have given negative results, so far as the absorption is concerned, though the lines seem to stand out more clearly against the background of continuous spectrum when self-induction alone is used. A direct current spark in water and in a 5 per cent. solution of $BaCl_2$ gave similar effects at the positive and negative poles. These experiments, and those on self-induction, are regarded as inconclusive, and will be repeated with better apparatus.

The investigation will be continued with the assistance of Dr. N. A. Kent, to whom I am indebted for efficient aid in the work described above.

YERKES OBSERVATORY,
March 1, 1902.

# *MINOR CONTRIBUTIONS AND NOTES*

## FURTHER OBSERVATIONS OF THE MOVEMENTS AND CHANGES IN THE NEBULOSITY ABOUT *NOVA PERSEI*.[1]

AN examination was recently made, in the course of another investigation, of the series of negatives of *Nova Persei* secured with the Crossley reflector in February and March, 1901, by Messrs. H. K. Palmer and C. G. Dall. I found that a plate taken on March 29 with an exposure of ten minutes showed two faint rings of nebulosity about the *Nova*, as well as several masses in its vicinity. This negative carries back our knowledge of this interesting nebula nearly five months. The early observations of the nebula thus far reported are as follows :

1901 March 29, Lick Observatory.
1901 August 23, Heidelberg Observatory.[2]
1901 September 20, Yerkes Observatory.[3]

The following list of negatives of *Nova Persei*, showing the nebulosity, have been obtained with the Crossley reflector :

| No. | Date 1901 | P. s. t. of exposure | Duration of exposure |
|---|---|---|---|
| 1 | March 29 | $7^h$ $57^m$ to $8^h$ $7^m$ | $0^h$ $10^m$ |
| 2[4] | November 7 | 10 47 to 15 21 | 7 19 |
| | " 8 | 10 0 to 13 0 | |
| 3 | " 12 | 9 45 to 14 45 | 10 0 |
| | " 13 | 9 29 to 14 29 | |
| 4 | December 4 | 7 48 to 13 16 | 5 28 |
| 5 | " 8 | 7 37 to 13 7 | 10 0 |
| | " 11 | 7 29 to 11 59 | |
| | 1902 | | |
| 6 | January 2 | 6 18 to 11 18 | 10 0 |
| | " 3 | 6 31 to 11 31 | |
| 7 | " 10 | 6 27 to 11 57 | 10 30 |
| | " 11 | 6 37 to 11 37 | |

[1] *Lick Observatory, University of California, Bulletin* No. 14.

[2] *Astronomische Nachrichten*, No. 3736. [3] ASTROPHYSICAL JOURNAL, **14**, 167.

[4] The exposure of November 7 was interrupted 15 minutes near the middle.

The following approximate coördinates of some of the principal condensations are deduced from the negative of December 8–11. These coördinates refer to the *Nova* and are intended for purposes of identification only.

NEGATIVE NO. 5.

| Condensation | p. | s. |
|---|---|---|
| *A* | 127° | 8′.9 |
| *B* | 153 | 7.5 |
| *C* | 186 | 6.8 |
| *D* | 210 | 1.6 |
| *E* | 211 | 13.5 |
| *F* | 350 | 15.4 |
| $F_1$ | 357 | 15.7 |
| $F_2$ | 0 | 14.8 |
| *G* | 259 | 13.6 |
| *H* | 279 | 8.5 |
| *I* | 291 | 6.8 |
| *J* | 335 | 6.8 |
| *K* | 0 | 6.8 |

DESCRIPTION OF NEGATIVES.

*No. 1, March 29.*—The principal ring of nebulosity about the *Nova* is not circular, but is an irregular oval considerably flattened on the southwest side. The longer axis of the oval lies in position-angle 115°. Following are the distances of this ring from the *Nova:*

| | |
|---|---|
| N. E. | 2′.2 |
| S. E. | 2.1 |
| S. W. | 1.5 |
| N. W. | 2.2 |

The ring is best defined in the S. W. and N. W. quadrants, where it is 20″ in width. At the ends of the oval the nebulosity is more diffuse and not so well defined, resembling somewhat the Annular Nebula in *Lyra*.

Inside this principal nebulous ring is another much closer to the star, and much fainter. The smaller one is apparently a perfect ellipse, the *Nova* being in one focus. The major axis of this elliptical ring is in position-angle 60°, its length being 2′.5. The minor axis is 2′.0 in length. The star is situated ¾′ from the S. W. end of the ellipse. Condensation *D* appears to form the S. W. portion of this inner ring and to be a miniature of its present shape.

To the south of the *Nova*, at a distance of 3′, is a mass of very faint nebulosity exhibiting an arrow-headed structure similar to that of condensation *A*, and pointing in the same direction. By means of motions deduced from the later photographs this arrow-headed condensation is traced backward to the vicinity of that noted on the negative of March 29. The distances agree more closely than the directions, on the assumption of uniform rectilinear motion.

In the northeast quadrant there is a narrow wisp of nebulosity having the form of an arc of a circle of 5′ radius, with *Nova* at the center. This wisp is of uniform curvature and width, and extends from 0° to 90° of position angle.

*No. 2, November 7–8.*— It was an examination of this negative which led me to the discovery of motion of several of the principal condensations about the *Nova*. Having been taken on a less rapid plate than the later ones, it does not show all the detail that is visible on most of them. The principal condensations are very distinct, however, and much faint detail is seen in the region of 7′ radius surrounding the *Nova* (See *Bulletin* No. 10).

*No. 3, November 12–13.*—This negative, taken on a quicker plate and with a longer exposure, shows greater strength in the principal condensations, as well as more detail in the region about the *Nova*. This area is approximately circular, with a diameter of 15′, and is the region in which Mr. Ritchey of the Yerkes Observatory photographed nebulosity on September 20.

To the south of *Nova* are shown the principal condensations previously referred to, as well as a number of wisps between the outer edge of this area and the star. The displacement of condensation *A* is perceptible in the interval of five days. To the west of the star are several arrow-shaped masses pointing northwest. There are several narrow wisps of nebula to the north concentrically curved about *Nova*. One of these, at a distance of 7′, covers an arc of nearly 90°. Outside of this is a streamer extending from the region of *D* outward, perhaps spirally, counter-clockwise, to position-angle 0°, or over an arc of 140°.

To the east of *Nova* are a number of irregular masses, many of them connected together, but not indicating clearly any regular structure.

Outside of this comparatively well-defined area 15′ in diameter is another area of about 30′ diameter showing traces of very faint nebu-

losity. This is most distinct in the region from 270° to 90°, which is practically filled with it. Scarcely any trace of this exterior nebulosity is to be seen to the south and southwest on this negative. On the outer edge of this larger area, to the north, there are traces of several short wisps or lines (*F*), forming a portion of a rim as it were.

*No. 4, December 4.*—While this negative had an exposure of only $5^h\ 28^m$, and in a sky with some haze, as evidenced by the halation ring about the star, the principal features of the nebulosity are well shown. In condensation *A* there are signs of a separation of the fainter envelope from the brighter forked mass which it surrounds.

In position-angle 211′, and at a distance of 13′.5 from the star, there is a short wisp of nebulosity (*E*) that is not visible in the previous negatives. This wisp forms the arc of a circle about the star and is between 2′ and 3′ in length. Just inside of this wisp there are traces of one or two others, more or less concentric.

*No. 5, December 8–11.*—The motion in the interval of three days between the two parts of the exposure, caused by a period of stormy weather, was sufficient to blur the finer details. This is especially the case in condensation *A*. The wisps *E* and *F* are stronger and more pronounced than in the negative of December 4.

The faint outer nebulosity is most pronounced on this negative, being easily seen all around the *Nova*, but is strongest in the southeast quadrant, where it can be traced 18′ from *Nova*. Outside this area, and extending to the limits of the field to the east and southeast, are irregular masses of nebulous matter, some of them connected with the main area.

Perhaps the most interesting region of this outer nebulosity is that to the west of *Nova*. In this area, especially near the edge, is a perfect network of the finest detail on the plate. Composed of the faintest and finest thread-like filaments in all directions, it is useless to attempt a full description. Attention may be called, however, to an arrow-shaped mass (*G*) of these filaments to the west at a distance of 13′.6 from *Nova*. It is composed of several layers of filaments with others irregularly crossing, its axis being directed counter-clockwise. Some evidence of a similar network of these filaments is found in other parts of the outer nebula.

*No. 6, January 2–3.*—The conditions under which this negative was obtained were very unfavorable, the seeing being decidedly bad, with a high north wind which shook the telescope at times, notwith-

standing the wind screen. The star images are large and fuzzy and the fine details considerably blurred. However, the general features are well shown, and the wisps at *E* and *F* are easily distinguished. These show considerable displacement during the interval,

*No. 7, January 10–11.*—The conditions under which this negative was secured were good. The star images show that the focus of the telescope was not good at all times during the exposures, but the various features of the nebulosity are well recorded, although not perfectly sharp. The motions of condensations *A*, *B*, and *C* continue. The envelope about condensation *A* has separated farther from the brighter nucleus. The nucleus itself has separated into two portions, the whole being considerably fainter. Several new wisps and small masses have appeared to the south and west of *A*. Condensation *B* is little changed in form, but is weaker, as is also condensation *C*. Condensation *D* remains practically unchanged both in form and intensity.

Condensations *E* and *F* are quite well marked, as is also the western edge of the outer nebulous area.

SUMMARY.

A comparison of the negatives obtained between November 7 and January 10, inclusive, indicates a general expansion of the nebula in all directions. The motions of several of the best-defined masses of the inner circle of nebulosity, to the south of the star, are in a clockwise direction. To the west, at least one mass appears to have a counter-clockwise motion.

A comparison of the positions of the principal condensations, *A*, *B*, and *C*, as deduced from the plates of November 7–8 and January 10–11, indicates the following motions during the interval. Condensation *C* has undergone a change, principally in brightness, such that the latter position of this mass is somewhat uncertain.

| Condensation | Direction of motion Position angle | Distance moved |
|---|---|---|
| *A* | 104° | 1′.2 |
| *B* | 116 | 1.0 |
| *C* | 178 | 1.6 |

In the outer ring of nebulosity the wisps marked *E* show a counter-clockwise motion, while the group marked *F* indicates a clockwise motion. In both cases a general expansion outward is shown, but the

larger component of motion is tangential and amounts to about 3′ in the interval December 8–11 to January 10–11.

From the rapid changes in form and intensity all determinations of position are subject to a large probable error. A comparison of the nebular rings recorded on March 29 with those obtained recently points to an intimate connection. The two groups of nebulous wisps, *E* and *F*, observed in December and January, show a radial component of motion for each group of ¾′ to 1′ in the interval of one month. It seems probable, therefore, that the two rings observed on March 29 have expanded into the later appearances, and that these two groups, *E* and *F*, are fragments of the outer ring of the earlier date.

A simple computation shows that the distances of the outer ring of March 29 and the two groups, *E* and *F*, from the Nova are approximately proportional to the intervals of time, from about February 20, assumed as the date of the outburst.

Upon the assumption of identity of these appearances the daily radial rate of recession is found, from the interval March 29, 1901, to January 2–3, 1902, to be $2''.62$ for the mass *E* in the southwest quadrant, and $3''.00$ for the mass *F* to the north. These values of the daily motions give February 16 as the date when mass *E* occupied a position apparently coincident with the star. For mass *F* we find in the same way February 17. Using the brighter nebular ring of March 29, we also obtain February 16 and 17 as the dates, respectively, when these portions of the ring occupied the same position as the star. The two sets of results agree within a tenth of a day, but this must be considered accidental, as the measures upon which they rest were made only to the nearest tenth of a minute.

If this nebula is expanding in all directions, and should continue to expand at its present rate, some of it should reach the solar system in 250 years.

It is planned to publish photographs and measures of the nebula at an early date.

C. D. PERRINE.

JANUARY 13, 1902.

## A DETERMINATION OF THE CAUSE OF THE DISCREPANCY BETWEEN MEASURES OF SPECTROGRAMS MADE WITH VIOLET TO LEFT AND WITH VIOLET TO RIGHT.[1]

It has been observed here and elsewhere that in measuring spectrograms for determination of velocity in the line of sight, a systematic difference is found in the determinations, amounting to perhaps one kilometer per second on the average, depending on whether the plate is measured with the violet end to the left or to the right. More precisely, there is a tendency to set the cross-hair a little too far to the right (as seen in the microscope) on the comparison-lines, or to the left on the star-lines. For this reason each plate is measured once with the violet to the left and once with the red to the left, and the finally adopted value for the line-of-sight velocity with reference to the observer is the mean of the two determinations. The method in detail is this: First, the plate is set on the table of the measuring-engine with the violet end to the right (appearing to the left in the microscope-field), and suitable lines are measured throughout the length of the plate. In this position, readings of screw-divisions increase with increasing wave-lengths. The plate is then turned end for end and the same lines are remeasured. Suppose the readings for several lines in the first measurement are, respectively,

$$a_1,\ a_2,\ a_3,\ \text{etc.}\ ;$$

then, if settings were made with perfect accuracy, the readings for these same lines on the second measurement would be

$$b_1 = X - a_1,\ b_2 = X - a_2,\ b_3 = X - a_3,\ b_4 = X - a_4,\ \text{etc.}\ ,$$

where $X$ is a constant depending on the two positions in which the plate was set relatively to the screw. In actual cases, however, $a + b$ is not a constant. Let $a' = x + b$, where $x$ is any arbitrary number, preferably some round number not far from the average value $a + b$. Then $\frac{a + a'}{2}$ is the proper reading for the line (bearing in mind that only *differences* of screw-readings are of importance.) We have

$$\frac{a + a'}{2} = \frac{a + x - b}{2} = a + \tfrac{1}{2}[x - (a + b)]\ .$$

Therefore, if the sum of the two readings exceeds $x$ by an amount $\epsilon$,

[1] *Lick Observatory, University of California, Bulletin* No. 15.

we subtract from the first reading $\frac{1}{2}\epsilon$, or if it is less than $x$ by an amount $\epsilon$ we add $\frac{1}{2}\epsilon$. The systematic difference already spoken of between measures with violet to left and with violet to right amounts to this: the average sum $a+b$ is greater for the comparison-lines than for the star-lines. For, if $a_1$ is the first reading on a comparison-line, $a_2$ on a star line, $b_1$ and $b_2$ the corresponding readings after the plate is reversed, then

$$a_1 - a_2 > b_2 - b_1 , \text{ or } a_1 + b_1 > a_2 + b_2 .$$

Moreover,

$$(a_1 - a_2) - (b_2 - b_1) = (a_1 + b_1) - (a_2 + b_2) \ ;$$

so that if the mean value of the sum of the two readings is $P$ for the comparison-lines, and $Q$ for the star-lines, then $\Delta = P - Q$ may be taken as expressing in screw-divisions the difference between measurements of the Doppler-Fizeau shift as measured in the two ways. In my own measurements, $\Delta$ almost always lies between three and ten thousandths of a revolution of the screw, and usually is close to six thousandths; the pitch of the screw being 0.25 mm.

It was thought desirable to determine the cause of this effect, as it might possibly introduce systematic errors which are not eliminated by taking the mean; and a series of measurements was made with that end in view.

Three possible causes suggest themselves: first, the curvature of the lines, which is inappreciable in the narrow star-spectrum, but noticeable in the comparison-lines, especially if the slit is long; second, the fact that the star-spectrum is situated in the middle of the field, with the comparison-spectrum on each side of it; third, the fact that in one case the setting is made on a black line in a bright field, and in the other on a bright line in a dark field.

In order to determine the effect of curvature, the curvature was eliminated by fitting the spectroscope with a new slit which was itself curved in such a manner as to make the spectral lines straight. A trial plate taken with this slit showed no appreciable curvature of the lines, even when the slit-length was several times as great as is commonly employed. Using this slit, several plates were made for use in this investigation — in particular, one of the Moon and one of the star $\beta$ *Herculis*.

To see whether the second possible cause suggested above really exerts any effect, some plates were taken with the absorption-spectrum and the comparison-spectrum interchanged in position; that is, the

comparison was placed in the middle of the field, with the absorption-spectrum (that of the Moon, or of the sky in the day time) on each side of it. It is obvious that if the effect in question is entirely due to the usual arrangement in position of absorption-spectrum and line-spectrum, the average sum $a + b$ should in these plates be greater for the former than for the latter.

To determine whether the effect is due to a psychological tendency to set too far to the right on a black line in a white field (or too far to the left in the reverse case), a good plate was secured of the iron-spectrum, both in its usual position and also in the middle of the plate where the star-spectrum usually goes. To prevent the outside lines from forming a continuation of the lines of corresponding wave-length in the center of the plate, the plate was shifted lengthwise before the exposure on the center was made, so that the plate resembled a spectrogram of a nebula or star with very great radial velocity, giving the iron lines alone as a bright-line spectrum.

Several other plates were taken of the spectrum of light reflected from the sky with certain unexposed gaps (left by the interposition of a diaphragm properly filed), in which gaps the strongest of the lines of iron were afterwards inserted; thus giving on the same plate bright lines on a dark field and dark lines on a bright field, without any lateral displacement, so that all would be measured in the same part of the field of the microscope. If the effect in question is due entirely to a tendency to set differently on bright and on dark lines, we should expect the value of $\Delta$ to be the same for these plates as for those in in which the comparison is placed on the sides; while the plate containing only emission-spectra would have the average sum $a + b$ the same for inside lines (in the usual position of the star-spectrum) as for those on the outside.

Plates of these various kinds were measured at various times, from the latter part of August to the early part of October, and the quantity $\Delta$ determined for each one. The results made it tolerably certain that the effect was due entirely to the third cause. Still, there were certain discrepancies which I attributed to a secular change in my methods of measurement, but which were of such a character as to make it seem possible that the second cause also operated in a slight degree. For this reason, it was thought best to measure them again, and also between every two to measure one or more good plates of the usual kind, thus eliminating as far as possible the effect of any secular

change in habits of measurement. The following table shows the results of these measures, which may be accepted as final. The first column gives the date when the plate was measured. The second gives the description of the plate. When the plate is one taken on our regular program (as in the case of all the ordinary plates, and of two taken with the curved slit but otherwise in the usual way), it is designated by the name of the star and the number and letter given to the plate in the regular observing book for the Mills spectrograph. The other special negatives which are used only for this investigation, and were therefore not entered on the regular records, are designated by the date when they were exposed, and by a letter to distinguish between plates taken on the same day.

The third column is a description of the character of the different plates. Those marked with an asterisk are the ordinary plates, used as a check on changes in habits of measuring. The notes in this

| Date of measurement | Designation | Kind of plate | $\Delta$ |
|---|---|---|---|
| 1901 Oct. 28 | *α Tauri*, 2280 *D* | * | +6.2 |
| 28 | October 3, *F* | *Fe* inside and outside. | +1.0 |
| 29 | *β Capricorni*, 2197 *E* | * | +6.3 |
| 30 | October 3, *E* | Sky and *Fe*, both in middle. | +8.2 |
| 31 | *Venus*, 2290 *C* | * | +6.3 |
| Oct. 31–Nov. 1 | October 3, *D* | Sky and *Fe*, both in middle. | +9.3 |
| Nov. 2 | *Polaris*, 1853 *B* | * | +9.1 |
| 8 | *ζ Ceti*, 1858 *B* | * | +9.1 |
| 9–11 | August 30, $D_2$ | Moon outside, *Fe* inside, curved slit. | +7.7 |
| 12 | *Procyon*, 2292 *E* | * | +4.8 |
| 15 | *η Geminorum*, 2304 *B* | * | +6.2 |
| 18 | October 3, *F* | *Fe* inside and outside. | +2.0 |
| 19–20 | *Venus*, 1894 *B* | * | +5.2 |
| 20 | Moon, 1844 *A* | Moon outside, *Fe* inside. | +5.9 |
| 21–22 | *Venus*, 1656 *A* | * | +5.9 |
| 22 | Moon, 2249 *C* | Curved slit, otherwise as usual. | +3.8 |
| 23 | *Venus*, 1997 *A* | * | +4.0 |
| 26–27 | *Mars* 1976 *C* | * | +5.8 |
| 27–29 | *β Herculis*, 2245 *E* | Curved slit, otherwise as usual. | +6.5 |
| 30 | *Mars*, 2141 *C* | * | +5.7 |

column, referring to the other plates, scarcely need explanation. As an example, the note, "Moon outside, *Fe* inside, curved slit," means that the plate measured October 9–11 had the comparison spectrum in the middle, with the Moon-spectrum inclosing it on each side, and that the curved slit was used in taking this plate. When it is not specified otherwise, it will be understood that the straight slit was used. The

fourth column gives, in thousandths of a revolution of the screw, the the value of $\Delta$ — the difference between the average sum of the readings (with plate direct and with plate reversed) for the comparison-lines and for the absorption lines.

These results seem to point definitely to the conclusion that the effect is produced entirely by a tendency to set farther to the right on a dark line in a bright field than on a bright line in a dark field. It is true that the measurements of October 28 and November 18, in which the sum $a+b$ is a trifle less for emission-lines in the center of the plate than for the same kind of lines farther out, seem to throw doubt on this conclusion, but as there were comparatively few lines to be measured on this plate, and the results of the other plates agree fully with this conclusion, we may regard the discrepancy as accidental. Further evidence to this effect is found in the measurements by Mr. W. H. Wright, of this Observatory, of several photographs of the bright-line spectra of nebulæ. Here there are only emission-lines to measure, and we should expect, if our conclusion is correct, that there would be no difference between the average sum $a+b$ for the nebula lines and for the comparison-lines. His measurements on seven nebula plates give for the mean difference $+0.9$. In measuring ordinary star-plates Mr. Wright usually has a value of $\Delta$ at least twice as great as my own. We may therefore regard it as fairly certain that the difference between measures with violet to left and with violet to right is due solely to a tendency of the person measuring to set farther to the right on a dark line in a bright field than on a bright line in a dark field, without regard to the relative positions of the two in the field of view, or to the curvature of the lines. It may be said that this result was anticipated by us, but every care was taken to prevent personal bias from influencing the measures, and I believe them to be free from any such influence.

It certainly seems that no error is introduced by adopting the mean of measures made with violet to left and with violet to right, so that it is not worth while to seek any means of eliminating the discrepancy, especially as no ready method of accomplishing this presents itself.

The measurements of spectrograms of *Venus*, *Mars*, and the Moon made during the investigation were reduced by our usual methods and compared with the theoretical velocities, to see whether any connection could be established between the residuals and the corresponding values of $\Delta$. No relation between the two was apparent.

Several other methods for investigating the origin of this right and left discrepancy presented themselves to us. A very simple one consists in measuring, in the usual manner, a contact positive copy of an ordinary negative secured with the Mills spectrograph. Since the bright and dark lines of the negative would be transformed into dark and bright lines, respectively, on the positive, the right and left discrepancies of the two plates should have opposite signs, if our suspicions as to their origin were correct. It was originally intended that this method should also be included in the program, but the results described above were so definite that further investigations along this line were considered to be superfluous.

In conclusion, I wish to acknowledge my indebtedness to Director Campbell (at whose suggestion the investigation was undertaken) and to Mr. Wright, for valuable advice and suggestions.

H. M. REESE.

December 16, 1901.

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## ORIGIN OF A DISTURBED REGION OBSERVED IN THE CORONA OF 1901 MAY 17–18.[1]

IN my preliminary report[2] of the observations of the Sumatra eclipse by the Crocker expedition from the Lick Observatory, I called attention to an unusual area of disturbance in the corona in the northeast quadrant. At the time of writing that report no observations of the Sun's surface were available from which to investigate the source of this disturbance. Through the courtesy of the astronomer royal, Royal Observatory, Greenwich, we have received a set of positives on glass of negatives of the Sun taken at Dehra Dûn, India, on May 17, 18, 19, 20, 21, 22, 26, and 28, 1901. These photographs are on a large scale, 7½ inches to the Sun's diameter, and furnish the desired observations. They show an intimate connection between activity on the Sun's surface as observed in the Sun-spots and faculæ, and the corona.

The photographs of May 17 and 18 show no spots or other evidences of activity on any part of the Sun's disk. This absence of spots was noticed before the eclipse at the station in Sumatra. The photograph of May 19, however, shows a medium sized spot which has just come into view around the east limb. On this date the spot is little more

[1] *Lick Observatory, University of California, Bulletin* No. 18.

[2] *Lick Observatory Bulletin* No. 9.

than a line, owing to foreshortening, ½′ in length, surrounded by faculæ. On the 20 it is ¾′ in length (*i. e.*, north and south), followed at a distance of ½′ by several small spots forming a close group. On all sides of the group, except the preceding or west side, is a large area of faculæ. The principal spot is compact, with well defined umbra and penumbra, and shows no more changes from day to day than are usually observed in the same period. The group of small spots following, however, shows traces of greater activity, principally growth.

Following are the coördinates of the principal spot deduced from the plates of May 19 and 28, the longitude being measured from the center of the disk:

| | | Greenwich Civil Time | Longitude | Latitude |
|---|---|---|---|---|
| 1901 | May 19 | $3^h\ 30^m\ 37^s$ | 80°.7 East | +9°.0 |
| | 28 | 7 29 37 | 46°.7 West | +9.0 |

From these positions are deduced the following coördinates of the spot at the time of the eclipse in Padang:

| | | Greenwich Mean Time | Longitude | Latitude |
|---|---|---|---|---|
| 1901 | May 17 | $17^h\ 40^m\ 37^s$ | 93°.8 East | +9°.0 |

From this it will be seen that the spot was on the opposite side of the Sun at the time of the eclipse and within 4° of the limb. Following are the position angles of the spot as projected on the limb, and of the apex of the disturbed area in the corona observed on the eclipse negatives:

| | Position Angle |
|---|---|
| Sun-spot - - - - - - | 60°.2 |
| Apex of coronal disturbance - - - | 60°.0 |

During the period of eleven days covered by the photographs, only this one group of spots was visible. In this time almost the entire solar surface was under observation.

We see from the above position angles that this region of Sun-spots occupied the same line of sight as the apex of the disturbed coronal region. While it is true that we have no means of determining the exact position of the coronal disturbance in the line of sight, attention was called in *Bulletin* No. 9, to the probability that its origin was near the Sun's limb. As both Sun-spot and disturbance are shown to have the same latitude, it can hardly be doubted that this unusual appearance in the corona was in reality immediately above the group of Sun-spots

and faculæ, and that it had its origin in the same disturbance of the Sun's surface. The long, thread-like prominence to the south, seen projected almost tangentially from the Sun's surface, appears likewise to have emanated from the same group of spots and faculæ.

These observations furnish very strong evidence of the intimate connection of all solar phenomena. Sun-spots, faculæ, prominences and corona all seem, in the present case at least, to have had a common origin.

The appearance of this disturbed region in the corona, and its undoubted connection with the group of spots on the surface so strongly suggested great activity that an investigation was made as to whether there had been a measurable displacement of any of the coronal masses in this region. The interval of time between photographs of the corona available for this purpose was but little over five minutes, yet if the velocities were large, 50 or 100 miles per second, such motion should be easily detected. The results give no certain indication of motion in the interval. The uncertainties of measurement of these coronal masses is so large, however, that a velocity of 5 or 10 miles per second would not be detected in so short an interval of time. We may conclude that the velocity across the line of sight was less than 20 miles per second.

The interval of one and one-half hours between the times of the eclipse in Mauritius and Padang should render a comparison of negatives secured at these two stations valuable in this connection.

C. D. PERRINE.

February 9, 1902.

# *Reviews*

*Handbuch der Spectroscopie.* Von H. KAYSER. Erster Band. Hirzel, Leipzig, 1900.

THE year 1859 is not likely to be soon forgotten in the annals of science. For though many years separate Lamarck and Buffon from Darwin, and though nearly half a century intervenes between Fraunhofer and the work of Kirchhoff and Bunsen, we must still reckon from 1859, the establishment of the modern evolution theory and the discovery of modern spectroscopy. The forty years of history which have been made since then illustrate well the difference between ideas which deal only with "dead matter" and those which touch the life-history of the individual and of the race.

Since the *Origin of Species* was first published, the press has poured forth a stream of literature — of which a volume a day would probably not be an overestimate — dealing principally with the developmental hypothesis. On the contrary, one might almost count upon the fingers of his two hands all the treatises, popular or technical, dealing with the subject of spectrum analysis. Among the names which occur to everyone are Schellen, Roscoe, Lommel, H. W. Vogel, Schuster, Kayser (*Lehrbuch*), Scheiner, v. Konkoly, Young, Huggins, and Lockyer. Besides the volumes associated with these names, almost the entire literature of the subject is contained in highly specialized memoirs. Some faint idea of the extraordinary amount of spectroscopic work hidden away in the journals of chemistry, physics, and astronomy may be obtained from the fact that the author of the work under review finds no less than five octavo volumes necessary to contain a brief survey (*Uebersicht*) of what has already been achieved, and achieved principally in the last forty years.

Rarely has a more fortunate combination of talent and time ever been brought to bear upon such a task. For the author himself, one of the foremost spectroscopists of the world, frankly informs his readers that he has given to this work a large part of his time during the past ten years, believing that in so doing he was serving science to better advantage than in pushing his own investigations. Whether workers

in this science concur in this judgment, they must admit themselves under deep personal obligations to Professor Kayser for what must have been to him a deep personal sacrifice. To a man whose brain is full of unsolved problems, and who is well equipped for their solution, ten years is a long stretch; and the task is perhaps less than half completed.

The present volume deals only with the history of the subject and with the description and theory of the apparatus employed. But the completeness of the treatment is such that if the other volumes are carried out in the same manner, it will be practically possible to say that a certain experiment has, or has not, been tried according as it is, or is not, "found in Kayser."

The first chapter clears the ground for all those which follow by placing before the reader an outline history of the entire subject. This sketch, occupying some 128 pages, takes up all the more important advances included between the work of Newton and the discovery of Zeeman. The arrangement is in nearly chronological order of the men who made the advances.

The second chapter deals with the three principal methods of producing luminous vapors, namely, the flame, the arc, and the spark. The eminent propriety of beginning the actual discussion of the subject with such a chapter will appeal to everyone who agrees with the logic of one who makes the capture of the hare the first item in the recipe for rabbit pie.

The phase of the subject here treated is not the mechanics of luminosity, but rather the various radiant sources at our disposal in the laboratory. So far from being a mere description of apparatus, every page is marked by keen judicial opinions and exhaustive references. But amidst all this array of devices for producing light, the description of which occupies more than a hundred pages, nothing perhaps is so impressive as the large number of contradictory views and *apparently* contradictory facts, compelling the author to insist, time and again, upon our almost entire ignorance of what is going on in either arc or spark. Speaking of the discharge in a vacuum tube (p. 203) he says: "Wir bewegen uns fast durchweg auf dem Boden von Hypothesen, denen andere ziemlich ebenso gut berechtigte gegenüberstehen." Again (p. 243), speaking of the fickle character of this discharge: "Es darf freilich nicht vergessen werden, wenn man diese Veränderlichkeit der Geisslerröhren bespricht, dass sehr Vieles von unserer

mangelhaften Kenntniss der Gasspectra herrührt." And still again (p. 248), speaking of the effects of pressure, temperature, foreign gases, etc.: "Aber wir wissen über alle diese Verhältnisse noch so gut wie gar nichts."

The complexity of the process going on in a spark between pure carbon poles in ordinary (moist) air is strikingly illustrated by the list of spectra (p. 214) obtained by Eder and Valenta under these conditions, viz.:

1. The line spectrum of carbon.
2. The banded spectrum of carbon.
3. The cyanogen bands.
4. The line spectrum of air.
5. The banded spectrum of water vapor, together with hydrogen and oxygen lines.
6. The banded spectrum of nitrogen at the positive pole.
7. The emission spectrum of ammonia when the electrodes are moistened.
8. The spectrum of carbon monoxide in the aureole of the spark.
9. And, in closed vessels, the absorption spectrum of nitrous acid.

The student who first attempts the separation of some of these spectra is brought very keenly to realize the wide gulf which at some point exists between spectroscopic theory and spectroscopic practice.

The third chapter, written by Dr. H. Konen, of Bonn, is entirely devoted to one of the two dispersion pieces, viz., the prism. Besides a complete account of the history and literature of the subject, one finds here an exceedingly clear discussion of dispersion and deviation along the lines laid down by Czapski in his *Theorie der optischen Instrumente;* and, what is perhaps more important to the spectroscopist, a full account of the results of Helmholtz and Rayleigh concerning resolving power, purity, and intensity. A compendium so complete as this on the various forms of prisms ought certainly to prevent, in the future, the frequent duplication of work which this and the other chapters of this volume have made evident. One form of prism originally devised by Brewster is mentioned as having been reinvented by no less than three different men.

A fourth chapter of nearly a hundred pages devoted to the diffraction grating completes the discussion of dispersion pieces. Here we find four sections dealing in turn with the manufacture of gratings, plane gratings, curved gratings, and the echelon of Michelson. So far as your reviewer is aware, this is the only single volume, in any

language, which presents a fairly complete account of what is known about gratings. Fraunhofer's work naturally forms the introduction; and those who have not read Fraunhofer's original papers (or Ames' translation in Harper's *Scientific Memoirs*) will be astonished at the thoroughness with which he covered the entire field of the grating and with the variety of forms which he manufactured and studied.

Here, too, will be found Rowland's powerful paper on the plane grating (*Astronomy and Astro-Physics*, 1893). The reader who approaches this paper only through the German will remain blissfully unconscious of how much time Professor Kayser has saved him by filling in a number of gaps and by correcting numerous typographical errors in the original. Then follows Cornu's elegant method of discussing the focal properties of both plane and curved gratings in one general equation, a paper which was translated in *Astronomy and Astro-Physics*, 1894.

Instead of Rowland's original handling of the curved grating (*Phil. Mag.*, 1883) the author wisely adopts the totally different and more elegant treatment of Runge, already familiar to the spectroscopic world through Kayser's article in Winkelmann's *Handbuch*. Near the end of this chapter the author offers, from his own experience, some excellent suggestions regarding the adjustment of the concave spectrograph.

The fifth chapter, dealing especially with the design and theory of the spectroscope, contains, in its first section, a description of practically every type of spectroscope ever made, together with numerous ones that never have been made. The second section, dealing with the ideas of purity and resolving power, as introduced by Helmholtz and Rayleigh and extended by Schuster, is one of the most valuable in the entire volume. Here, too, will be found a systematic account of the masterly manner in which Wadsworth has cleared up and perfected this whole subject.

Space permits us barely to mention some of the more important topics treated in the remaining sections of this chapter, namely, the interferometer — and Michelson's analysis of individual lines — the work of Higgs, Abney, and Schumann, the measurement of spectrograms, the automatic comparator of Kayser, and the bolometer.

The sixth and last chapter deals with the latest and finest achievements of spectroscopy considered as a quantitative science: and if we admit that the question *how?* can seldom be answered until after

the question *how much?* has been answered, we may reckon this the most fundamental chapter in the volume. Your reviewer is not familiar with any opinion in the literature of physics which combines in greater degree a judicial attitude of mind, critical acumen and complete impersonality than does the author's survey of the work which has been done on the measurement of the absolute wave-length of light. Naturally Bell's determination is given first place among all values obtained by means of a grating. However, excellent reasons are advanced for thinking that the highest possible accuracy attainable with this instrument is one-tenth of an Ångström unit. Indeed, the discrepancy between the values of Bell and Michelson, for the absolute wave-length, may be considered a closed chapter. For here one may find the facts concerning the grating and may find also that Michelson, in the superb and powerful method which he employed at Breteuil, left no room for an error as great as the one-hundredth part of an Ångström unit, in his final figure.

The standard relative values of Rowland, together with the corrected wave-lengths for the iron lines recently given by Kayser, are next taken up. The volume closes with a brief review of measurements in the ultra-violet and in the infra-red. An ample index of authors and subjects saves one that final disappointment which too often accompanies the closing of an English or a French book.

Concerning the volume as a whole, a reader gets the impression that the author has gone through the entire periodical literature of physical science with a drag net from which nothing has escaped.

The result is that these pages contain some matters which will probably prove new to the most accomplished spectroscopists of the world. In short, the work is of such a character that its possession is not only desirable but indispensable to every serious student of this science.

H. C.

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In the department of *Minor Contributions and Notes* subjects may be discussed which belong to other closely related fields of investigation.

Articles written in any language will be accepted for publication, but unless a wish to the contrary is expressed by the author, they will be translated into English. Tables of wave-lengths will be printed with the short wave-lengths at the top, and maps of spectra with the red end on the right, unless the author requests that the reverse procedure be followed. If a request is sent *with the manuscript* one hundred reprint copies of each paper, bound in covers, will be furnished free of charge to the author. Additional copies may be obtained at cost price. No reprints can be sent unless a request for them is received before the JOURNAL goes to press.

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